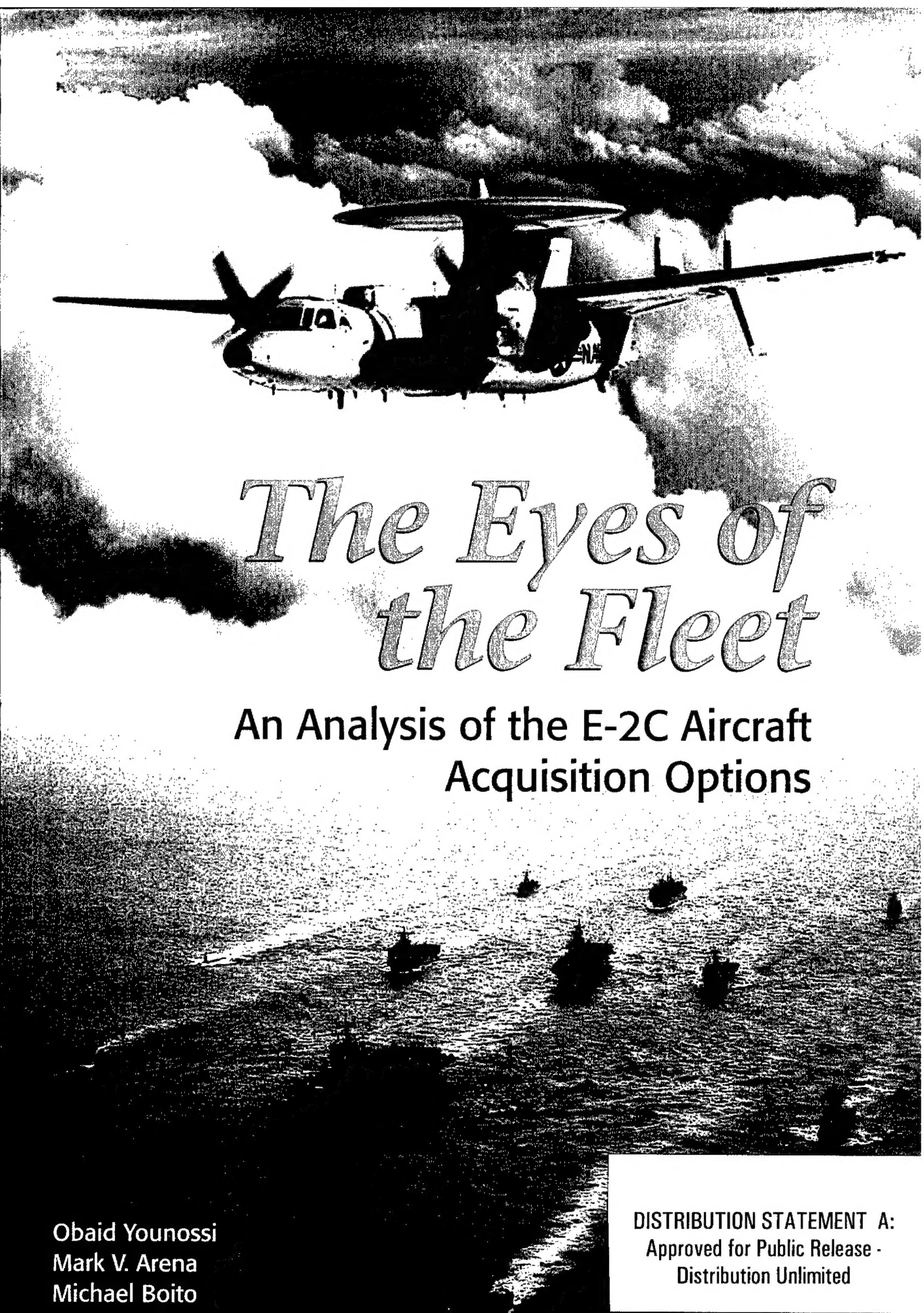

The Eyes of the Fleet

An Analysis of the E-2C Aircraft Acquisition Options

Obaid Younossi
Mark V. Arena
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Prepared for the

United States Navy

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PREFACE

The U.S. Navy's E-2C Hawkeye aircraft provides airborne early warning for the Navy's carrier battle group. A portion of the fleet is currently being replaced with a more capable version of the aircraft, the Hawkeye 2000. However, even with this improvement, the aircraft will not be able to deliver the operational performance the Navy believes it will need in the future. Furthermore, many of the aircraft in the current fleet are approaching their service life limits. Thus, the Navy has to decide whether to buy new aircraft, refurbish old ones, modernize portions of the E-2C fleet, or adopt some combination of these strategies. It must make a decision relatively soon if it is to keep enough aircraft to meet its operational requirements. This report analyzes the costs, benefits, and risks of some of the options the Navy might consider.

This report should be of interest to the Office of the Secretary of Defense and to Navy policymakers involved in the present and future direction of naval aviation. This research was carried out in the Acquisition and Technology Policy Center of the National Defense Research Institute, RAND's federally funded research and development center supporting the Secretary of Defense, the Joint Staff, the unified commands, the defense agencies, and the Navy.

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SUMMARY

The E-2C Hawkeye is the U.S. Navy's all-weather, carrier-based airborne early-warning (AEW) aircraft. Additional missions for which the E-2C is used include surface surveillance coordination, strike and interceptor control, search and rescue guidance, and communication relay. It is an integral component of the carrier air wing.

The basic E-2C model is a relatively old design, having joined the fleet in the early 1970s. However, it has been improved several times, and the most current version, the Hawkeye 2000 (HE2000) now in production, represents the fifth E-2C model. The current production model adds a sensor networking system known as cooperative engagement capability (CEC), which provides all members of the network (ideally all members of the carrier battle group) with a real-time combined radar/identification friend or foe (IFF) picture of the tactical air environment. Northrop Grumman Corporation (NGC) is under contract to deliver 21 of these aircraft to the Navy. The first of these aircraft was delivered in October 2001, and the final one is scheduled to arrive in 2006.

E-2C FLEET MODERNIZATION AND ACQUISITION OPTIONS

Meeting the Navy's day-to-day operational needs requires 63 active or deployable E-2Cs. The Navy also asserts that it must have a minimum fleet of 75 aircraft to have at least 63 E-2Cs operational at any one time. The extra aircraft are needed because not all aircraft are always available to fly. Some are undergoing periodic maintenance or repair, and others are used for research and development. The

current E-2C fleet comprises several different models and several variants within some models. Currently, the Navy has only 67 E-2C aircraft, which is far fewer than the 75 required.

The current E-2C fleet will not satisfy all the future requirements the Navy projects it will have to meet, even with the CEC capability. The Navy's analysis of future threats and missions indicates that its aircraft will have to operate over littoral areas and over land (Navy Public Affairs Library, 1993). The current radar on the E-2C (radar model APS-145), while adequate for operations over water, does not deal well with the ground clutter associated with littoral regions and land. Thus, the Navy has been investing in a radar modernization program (RMP) with an eye to either replacing the radar and other electronics on the current fleet of aircraft or procuring new aircraft that are equipped with the new radar.

However, the RMP technology has to mature before the Navy can employ it; therefore, it is not expected to be available before 2008. As with any new development, the RMP technology has certain risks associated with it—for example, the airframe modification and qualification may require additional time and resources. A further complication is that the RMP will add about 2,500 pounds[1] to the aircraft. This added weight has important implications for any modernization program because it is not clear whether the current airframe can sustain the additional weight. Therefore, considerable airframe modification and requalification[2] may be required. Simultaneously, the Navy would like to retrofit the non-HE2000 aircraft with the CEC capability.

Further complicating the issue is that a number of the aircraft in the current E-2C fleet are aging and nearing the end of their projected service life of 10,000 flying hours. These aircraft either need to be replaced with new aircraft or have their life extended by means of a life extension program that involves replacing and upgrading selected components.

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[1]This weight is an NGC estimate and the Navy had not assessed the weight increase independently when this study was completed.

[2]*Qualification* refers to the series tests to approve the aircraft for military and aircraft carrier operations.

Thus, the Navy has several options for modernizing or extending the life of the E-2C fleet:

- Extending the service life of aircraft approaching the 10,000-hour limit and retrofitting E-2Cs with CEC if they don't already have that capability
- Procuring new HE2000 aircraft
- Extending the service life of older aircraft by modernizing them through the addition of CEC capability (for those that lack it) and the addition of RMP radar and electronics
- Procuring new aircraft with RMP radar and electronics and CEC capability
- Or using some combination of service-life extension, retrofitting, and procuring of new aircraft.

Each option has different costs and benefits, and weighing one against the others is a fairly complex undertaking. Two additional factors complicate the situation even further. First, any option selected must enable the Navy to meet its operational requirements. That is, the Navy must have 63 aircraft operationally available at all times. Second, industrial base issues must be factored into the selection process. Presently, E-2C aircraft are built at only one facility: NGC's factory in Saint Augustine, Florida. The future of this facility depends almost entirely on the E-2C production; therefore, any option must take into account the industrial base implications.

STUDY OBJECTIVES

The Navy asked RAND's National Defense Research Institute (NDRI) to help it sort through the various options.[3] In addition to addressing issues of cost, scheduling, and technical feasibility of the E-2C fleet options, it also asked NDRI to consider the effect on the industrial base, specifically NGC's Saint Augustine facility. Accordingly, we focused our research on the following four issues:

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[3]The project was initiated in April 2001 and the final results were briefed to the project sponsor, the E-2C program manager, in August 2001.

- The engineering challenges associated with extending the life of the aircraft and upgrading the aircraft's mission capability with CEC and RMP technology
- The effect of the life extension and upgrade programs on operational aircraft availability
- The life-cycle costs of the various options
- The implications of the life extension and upgrade programs on NGC's Saint Augustine facility and key equipment suppliers for the E-2C program.

FINDINGS

The results of our analysis produced the following major findings:

- None of the life extension and upgrade programs can sustain the current minimum number of aircraft required to meet operational requirements over the service life of the program unless the Navy buys some new E-2C aircraft.
- Extending the service life of the current aircraft and upgrading them with CEC and RMP radar is not cost-effective compared with buying new aircraft with similar capability.
- The RMP poses both technical and program challenges. The technical challenge is that the capabilities of the new radar remain to be demonstrated. The program challenge is that the new radar increases the aircraft weight by more than a ton, which raises issues for any modernization program, including one for new aircraft.
- A relatively stable flow of E-2C work is essential to the survival of NGC's Saint Augustine facility, and a workflow at that level is not feasible with life-extension work alone.

Certain cost implications are inherent in each choice. Table S.1 summarizes the overall cost analysis results. The bottom row of the table shows the cost per additional hour of aircraft life for each option. The options include adding CEC or RMP through a structural life extension program (SLEP)/modification or by procuring new

Table S.1

Overall Cost Analysis Results per Aircraft (in FY2000 dollars)

	CEC		RMP	
	SLEP/ Modification	New	SLEP/ Modification	New
Aircraft service life in hours	5,000	10,000	5,000	10,000
Aircraft service hours per year	480	480	480	480
Procurement cost ($M)	47.1	80.0	74.5	90.0
Discounted operation and support cost per year ($M)	5.9	5.4	5.6	5.3
Procurement cost per hour ($K)	9.4	8.0	14.9	9.0
Operation and support cost per hour ($K)	12.3	11.3	11.7	11.0
Total cost per hour ($K)	21.7	19.3	26.6	20.0

aircraft. These figures were calculated to facilitate cost comparisons across options and should not be interpreted as budgetary costs.

RECOMMENDATIONS

Our recommendations depend on the specific goal the Navy wants to accomplish. If the Navy simply wishes to install the CEC capability on the fleet, we have one set of recommendations. If, however, the Navy wants the fleet to have the capability of operating in littoral areas, it should follow a different path.

If the Navy wants to modernize its entire fleet with CEC equipped aircraft it should consider a combination of service life extension plus CEC retrofit of two aircraft per year and procuring two new HE2000s in the short term. This is the most cost-effective option, and also maintains the operationally available aircraft levels of the fleet at or above 63 and helps to address the NGC–Saint Augustine industrial base issue.

If the Navy determines that littoral capability is necessary for its future operations, then it should use a combination of service life ex-

tension plus CEC retrofit of the fleet and new production. This option should be used only as a production-gap mitigation strategy to maintain the fleet readiness level and preserve the Saint Augustine industrial base until the RMP program development is complete. Additional airframe design and testing efforts to accommodate the RMP may require additional budgeted time and funding. Also, the Navy should buy only new RMP aircraft because RMP retrofit modification is relatively costly. This strategy would maintain an operationally available fleet of 63 aircraft, solve industrial base concerns, and provide additional performance capability to the future Navy warfighters.

However, before spending additional money to modify the current E-2C airframe to accommodate the additional weight of the RMP, the Navy should consider the costs and benefits of a new E-2C airframe design. The new airframe design could provide additional opportunities for future enhancements and incorporate producibility improvements through modern design approaches and manufacturing techniques.

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This study greatly benefited from the assistance of many people in the Naval Air Systems Command (NAVAIR), OPNAV, and Northrop Grumman Corporation.

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We wish to thank our RAND colleagues Irv Blickstein and Jack Graser for their thorough review of the draft document that significantly improved the clarity of this report. We are also grateful to our other

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ACRONYMS

AEW	Airborne early warning
CAINS	Carrier Aligned Inertial Navigation System II
CEC	Cooperative engagement capability
FY	Fiscal year
HE2000	Hawkeye 2000
IFF	Identification friend or foe
LCC	Life cycle cost
LMDSS	Logistics Management Decision Support System
LOE	Level of effort
MCU	Mission computer upgrade
NAV	Navigation
NAVAIR	Naval Air Systems Command
NDRI	National Defense Research Institute
NGC	Northrop Grumman Corporation
O&S	Operation and support
OWP	Outer wing panel
PAA	Primary Aircraft Authorization
PDM	Programmed depot maintenance
PMA	Program Manager Air

RDT&E	Research, development, test, and evaluation
RMP	Radar modernization program
SATCOM	Satellite communication
SD&D	System development and demonstration
SEPM	System engineering and program management
SLEP	Structural Life Extension Program
SLEP/MOD	Structural Life Extension Program/Modification
STAP	Space-time adaptive processing
TAAI	Total Authorized Aircraft Inventory
TCR	Time compliance requirement
T/M/S	Type/Model/Series
TSH	Test spectrum hours
TSPR	Total system performance responsibility
USDAT&L	Undersecretary of Defense for Acquisition, Technology, and Logistics
VAMOSC	Visibility and Management of Operating and Support Costs
WCS	Wing center section
WSPD	Weapon System Planning Document
WUC	Work unit code

Chapter One

INTRODUCTION

The E-2C Hawkeye is the U.S. Navy's carrier-based airborne early warning (AEW) platform. In this capacity, it performs a battle management role by providing real-time threat warning and tactical analysis to the battle group commanders and directs tactical response platforms and weapons to assigned targets. The E-2C Hawkeye supports anti-air, anti-surface, strike warfare, and amphibious/expeditionary forces in both naval and joint operational environments.

The E-2C is a high-wing aircraft with stacked radar antenna elements contained in a 24-foot rotating dome above the fuselage.[1] The aircraft is designed for a crew of five: pilot, copilot, radar operator, air control operator, and combat information center officer. The aircraft is powered by two turboprop T56-A-427 Rolls-Royce engines. The basic E-2C model is a relatively old design, having joined the fleet in the early 1970s. However, it has been improved several times, and the most current version, the Hawkeye 2000 (HE2000) now in production, represents the fifth E-2C model.

Northrop Grumman Corporation (NGC) is the prime contractor and system integrator of the E-2C aircraft and has had total system performance responsibility (TSPR)[2] since the inception of the program. Because the Navy did not purchase a detailed design-drawing

[1]For a fact sheet on the E-2C, see http://www.chinfo.navy.mil/navpalib/factfile/aircraft/air-e2c.html.

[2]TSPR refers to assigning total responsibility for all the factors that affect the performance of a system or a process to a contractor or a government organization.

package from NGC,[3] and whoever has TSPR needs detailed design information to maintain and support the E-2C aircraft, the program has never been competitively procured. Nor does the Navy anticipate a competitive procurement of the production and system integration of the E-2C in the future. Therefore, TSPR will remain with NGC (Naval Air Systems Command, 2001a).

E-2C PROGRAM BACKGROUND

The E-2C has been in production, albeit in small quantities, since 1961 as the E-2A and was updated in 1969 to the E-2B. The E-2C entered initial service in 1973. It has been produced in many different configurations and modified to incorporate updated electronics and subsystems.

The E-2C is currently produced at Northrop Grumman Corporation's Saint Augustine facility. This site is the third NGC facility used in the manufacture of the E-2C. The first facility was located in Bethpage, New York; production was then transitioned to Calverton, New York, and finally the operation was moved in 1994 and 1995 to Saint Augustine, Florida. The latest configuration, the HE2000, is procured under a multiyear contract, which began in 1998 and includes 21 new aircraft that provide cooperative engagement capability (CEC) to the fleet. The first of these aircraft entered the Navy fleet in October of 2001, and the last delivery is scheduled for 2006.

The Navy needs to maintain its current operational E-2C aircraft readiness needs, yet modernize its E-2C fleet to meet future deployment challenges as well. The Navy anticipates that this modernization of its E-2C fleet will be a valuable warfighting asset in the years ahead and will help to control escalating support costs from aging equipment.

The current E-2C inventory will not support operational, training, and maintenance requirements, summarized in Table 1.1, indefinitely. If the Navy does not procure new aircraft before fiscal year (FY) 2006 or modify the current ones, the fleet's available aircraft

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[3]This package is also referred to as a "level III drawing package."

Table 1.1

E-2C Total Inventory Requirements

	Number of Squadrons	Number of Aircraft in Inventory
Organization		
U.S. Navy	10	40
Fleet Readiness	I	12
U.S. Navy Reserves	2	8
Research, Development, Test, and Evaluation	N/A	3
Total (PAA)	13	63
Pipeline[a]	N/A	12
Total of PAA and pipeline	13	75

[a]Refers to the additional aircraft the Navy needs to maintain the fleet requirement of 63 while still allowing for routine servicing and maintenance.

inventory will fall below the Primary Aircraft Authorization (PAA)[4] level of 63 units by 2013 due to aircraft retirements at approximately 10,000 accumulated flight hours. Therefore, the Navy must buy new E-2Cs, extend the life of the current ones, or choose a combination of life extension and new production. But the problem is more complicated than that because the Navy would like to improve the E-2C's technical capability as well.

The capability the Navy would like to add first to the E-2C aircraft is CEC technology to all E-2Cs that do not currently have it. CEC is a segment of the ship self-defense system that provides all members of the network (ideally all members of the battle group) with a real-time combined sensor (radar/identification friend or foe [IFF]) picture of the tactical environment. CEC provides improved situational awareness, resource management for sensors and weapons, and a more complete tactical picture for all participants. These capabilities are accomplished through a coordinated sharing of the individual resources of all network members into a distributed common dataset. The E-2C, as the airborne CEC platform, is projected to

- extend the surveillance area for enhanced situational awareness

[4]The PAA level is the number of active aircraft that meets the Navy's operational and training needs.

- provide early warning of distant low-altitude targets
- allow for increased separation and coverage of the ships in the battle group while extending the network's line-of-sight communications.

This capability could be acquired either in conjunction with a life extension program or by purchasing additional HE2000s.

The CEC capability is not the only improved capability the Navy wants. It is also pursuing a radar modernization program (RMP) that will provide the E-2C with the capability to operate over littoral areas and over land. However, the RMP is in the early stages of development and is not expected to be fielded until 2008.

Therefore, the Navy has two basic options after the current multiyear contract ends in 2006:

- It can continue to populate the E-2C fleet with CEC-capable aircraft by (1) extending the life of the current fleet aircraft and upgrading them with the CEC mission electronics, (2) acquiring new HE2000s, or (3) using a combination of modification and new acquisition.
- Or the Navy could populate the E-2C fleet with RMP-capable aircraft by (1) extending the life of the aircraft in the inventory and upgrading the mission electronics, (2) buying E-2C aircraft equipped with the RMP radar, or (3) employing a combination of modification and new acquisition. (Because RMP will not be fielded until 2008, the modernization plan to fill the production gap should concentrate on pursuing CEC until the RMP comes on line.)

PURPOSE OF THE STUDY

The office of the Undersecretary of Defense for Acquisition, Technology, and Logistics (USDAT&L) tasked the Naval Air Systems Command's E-2C program office (Program Manager Air [PMA]-231) to examine the scheduling, cost, and technical feasibility of the options listed in this report. In addition, the E-2C program office was asked to assess the effects of the options on the industrial base, or more specifically, on the NGC–Saint Augustine facility. These options

include extending the airframe life of the current fleet through a structural life extension program (SLEP) and incorporating an avionics package providing the CEC or littoral capability that includes a new radar and electronics suite being developed through the RMP.

The Navy was concerned about how these options would affect the E-2C acquisition strategy and industrial base and asked RAND to help assess the costs and benefits of its strategy and plans for the future of the E-2C fleet. Therefore, we focused our research efforts on the following four issues:

- The engineering challenges surrounding the structural modifications required to extend airframe life and upgrade the mission electronics
- The constraints on the operationally available aircraft caused by implementing a SLEP and upgrade program
- The life cycle costs (LCCs) associated with each option
- The industrial base implications on Northrop Grumman Corporation and the E-2C's key equipment suppliers.

ORGANIZATION OF THIS REPORT

Chapter Two provides a brief history of the E-2C, tracing the size of the fleet and the aircraft models it comprises. Chapter Three discusses the technical considerations of the two major improvement programs for the E-2C, CEC, and the RMP. Chapter Four analyzes different life extension and modernization schedules with an eye to determining which ones can maintain the Navy's operational E-2C fleet at 63 aircraft. Chapter Five estimates the costs of the life extension and modernization options. Chapter Six examines the issues surrounding the industrial base, and Chapter Seven provides our conclusions and recommendations.

Chapter Two

DESCRIPTION OF THE CURRENT E-2C INVENTORY

This chapter provides a brief history of the size and composition of the E-2C fleet. It begins by tracing the changes that have occurred in the fleet size and noting the various roles that the aircraft has fulfilled. We then discuss the different aircraft configurations and conclude with an analysis of flight hours.

HISTORICAL E-2C REQUIREMENTS

The Navy divides its Total Authorized Aircraft Inventory (TAAI) fleet into two categories: PAA aircraft and "pipeline" aircraft. The *PAA level* is the minimum number of active aircraft required to meet the Navy's operational and training needs. *Pipeline aircraft* are those that are in the Navy's inventory but are not available for assignment to a squadron. They are additional aircraft the Navy needs to maintain the fleet requirement of 63.

The Navy needs pipeline aircraft because not every aircraft can fly every day. Some aircraft may be undergoing modification while others may be undergoing repair or scheduled maintenance. The Navy determines the number of pipeline aircraft based on the number of PAA aircraft. The pipeline aircraft can be thought of as the overhead necessary to keep the fleet at the minimum number of PAA aircraft. The number of aircraft in the inventory is described in the E-2C aircraft's Weapon System Planning Document (WSPD) dated May 5,

1999.[1] To meet its operational requirements, the Navy has determined that it needs 63 PAA aircraft and 12 pipeline aircraft for the E-2C fleet. Therefore, the total number of required TAAI E-2C aircraft is 75.

Table 2.1 summarizes the composition of the PAA. Essentially, each of the ten U.S. Navy squadrons requires four aircraft. The two Navy reserve squadrons (which also are assigned the anti-drug mission) also require four aircraft per squadron. There is also a fleet readiness squadron of 12 aircraft, which is used primarily for training. Last, three aircraft serve as test beds for research, development, test, and evaluation (RDT&E) efforts (such as the new, eight-bladed propeller and the CEC system). Thus, the PAA for the E-2C (active aircraft in the fleet) is 63 aircraft.

Figure 2.1 traces the decline of the E-2C inventory requirements over the past decade, from more than 120 TAAI aircraft (including the PAA aircraft) to the current level of 75 aircraft.

E-2C CONFIGURATIONS

Over time, the E-2C has evolved from a baseline configuration to Group 0, I, and II versions to the modern production version—the Hawkeye 2000. Figure 2.2 illustrates the evolution of the E-2C toward a more capable and sophisticated platform (the HE2000 enhancements reflect initial operating capability in 2002). Notably, most of

Table 2.1

E-2C Primary Aircraft Authorizations

	Number of Squadrons	Number of Aircraft
Organization		
U.S. Navy	10	40
Fleet Readiness	1	12
U.S. Navy Reserves	2	8
RDT&E	N/A	3
Total (PAA)	13	63

[1]The WSPD is a policy and planning document published by Naval Air Systems Command to provide guidance for the development, procurement, operation, and support of naval weapon systems (Naval Air Systems Command, 1999).

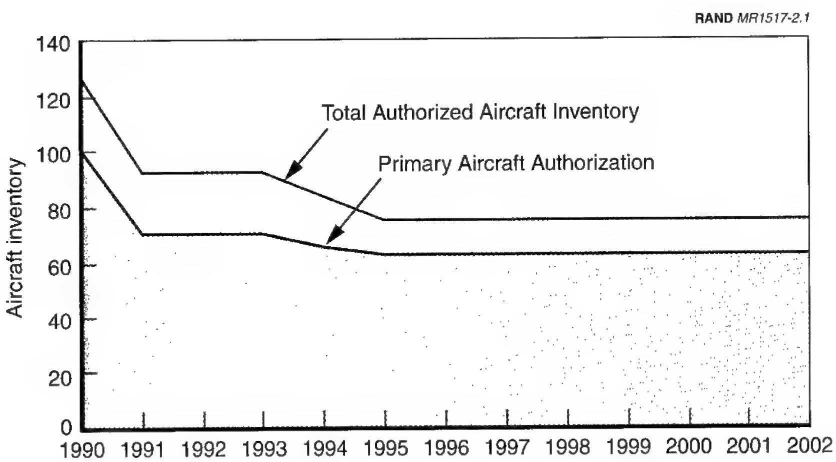

Figure 2.1—E-2C Total Aircraft Inventory Requirements (1990–2002)

the change has involved the mission systems (and their supporting equipment). The airframe or other systems have changed relatively little.[2] The oldest aircraft in the current E-2C fleet were first deployed late in 1980 and (as of this writing) the newest arrived in June 2001. Not surprisingly, the current fleet is composed of several configurations of E-2C aircraft. Table 2.2 shows the notional distributions of E-2C configurations in 2001.[3] Notice that the Group II aircraft configuration dominates the inventory. Moreover, four configurations constitute the Group II aircraft: Basic, navigation (NAV), mission computer upgrade (MCU), and TE-2C.[4]

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[2]The T56-A-427 engine, which was introduced in 1986, and the new propellers that are part of the current HE2000 design are examples of changes in systems other than avionics.

[3]Group 0 aircraft contain the APS-138 radar, which can detect low-flying targets over land as well as over water. Group II aircraft have been upgraded to contain the APS-145 radar, which provides extended capabilities. Group II aircraft also feature improved avionics and T56-A-427 engines. There are two Group II configurations: the navigation upgrade and the mission computer upgrade. Group I was a transitional configuration that is no longer active.

[4]The NAV configuration incorporates updated navigational systems. The MCU configuration incorporates a new mission computer and new tactical workstations, commonly referred to as Advanced Control Indicator Set (ACIS), and TE-2Cs are specially designed for training purposes.

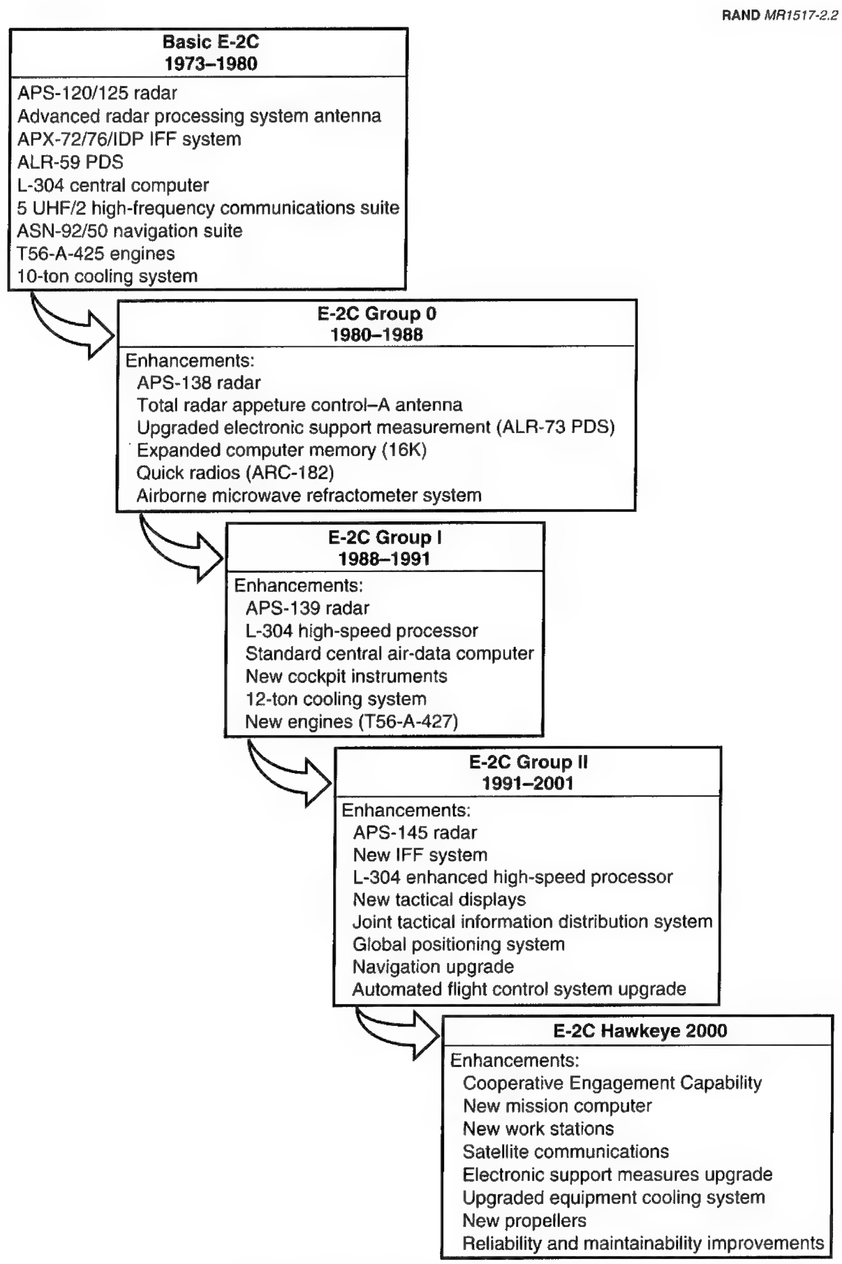

Figure 2.2—Evolution of the E-2C

Table 2.2

Notional Configuration of Active Inventory (end of 2001)

Configuration	Number of Aircraft
Group 0	16
Group I	1
Group II	
Basic	23
NAV	18
MCU	6
TE-2C	2
HE2000	1
Total	67

FLIGHT USAGE

Aircraft life is typically defined in terms of total flight hours. The projected life of an aircraft is based on fatigue testing and engineering analysis, which we discuss in detail in Chapter Three. Fatigue and damage accumulate as an aircraft ages. For the E-2C, the current life limit is 10,000 total flight hours.[5] Once an E-2C reaches this limit, the aircraft must be retired or undergo a SLEP. Figure 2.3 plots average monthly flight time against aircraft age in months for the three groups of active E-2Cs (we have omitted the aircraft in storage). The weighted average length of use of each aircraft is about 37 hours per month, with the newer aircraft being flown at significantly higher rates.

As can be seen in Figure 2.3, the average flight hours per month decline with age. There could be several reasons for this trend. One reason is that the Navy prefers to fly the newer aircraft, making use of the more up-to-date systems and capabilities of those aircraft. Another possible reason is that the newer aircraft are more reliable and therefore more available for flight. Another explanation is that as the older aircraft undergo extensive upgrades and modifications the aircraft are not flown, so no flight time would be logged, thus reduc-

[5]The average life of the E-2C aircraft that were retired from January 1973 to March 1992 was about 6,800 flight hours, excluding the lost hours due to crashes and hours spent in storage.

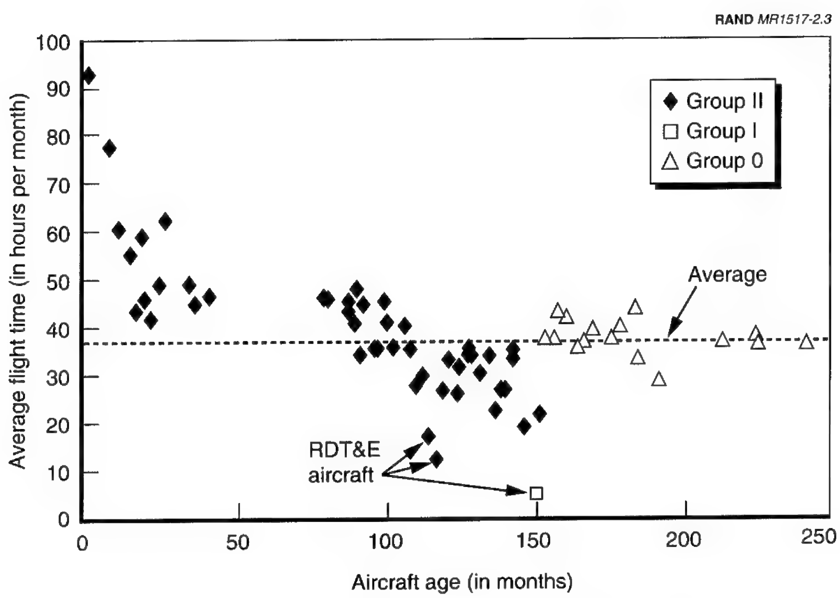

Figure 2.3—Average Flight Time by Individual Aircraft Age

ing the average monthly flight hours. Similarly, the E-2C undergoes programmed depot maintenance (PDM) every 40 months. The newer aircraft would have undergone relatively few (if any) maintenance events and therefore they would have a higher flight-hour-per-month average.

E-2C INVENTORY PROJECTION

We project that by 2014 the E-2C aircraft inventory will fall below the PAA level of 63 aircraft. In addition, we project that the inventory never attains the TAAI level of 75 aircraft over the next 30 years, so the requirement for the 12 pipeline aircraft is never satisfied (Chapter Four covers these projections in more depth).

These projected numbers present a significant constraint on any option for the SLEP/upgrade for the E-2C. If there aren't enough planes to meet the TAAI and if in addition fleet planes are pulled for modification, the inventory will fall below the PAA requirement even sooner. This issue is discussed in detail in the next chapter.

Chapter Three

TECHNICAL ANALYSIS OF THE E-2C UPGRADES

This chapter describes the technical considerations associated with the two major upgrade programs for the E-2C: the CEC and RMP technology upgrades. Although these two programs pose very different levels of risk in terms of cost and time schedules, they both lie at the heart of the E-2C modernization options available to the Navy.

The Navy currently is purchasing new HE2000-version E-2C aircraft, but by the end of the contract deliveries only 23 aircraft in the entire fleet will have CEC. The Navy could choose to retrofit the remainder of the fleet with CEC technology. In doing so, the Navy could also extend the life of airframes nearing their life limit by about 5,000 hours. (Later in this chapter, we describe the types of life-extension programs that would be required for the various airframe components.)

However, the Navy is also interested in the RMP-capable E-2C because it provides a new radar system plus improved electronics that can operate in littoral regions, which the current E-2C cannot. Thus, the Navy could retrofit E-2Cs with CEC if they don't already have that capability, extend the life of all airframes, and add the RMP capability to all E-2C aircraft. This option poses more risks in terms of cost and time schedules than the option of just adding CEC because the RMP technology has not been fully developed and because the new radar and electronics add about 2,500 pounds to the aircraft weight.[1]

[1]The 2,500-pound weight increase is based on an NGC preliminary estimate.

In addition, the ramifications of the additional weight have yet to be fully analyzed.[2] We address the RMP program later in this chapter.

E-2C AIRFRAME STRUCTURE LIFE LIMITS

The E-2C airframe underwent a full-scale fatigue test in the early 1990s as part of an overall SLEP analysis. The current airframe life limits are based on the results of that test, from which the Structures Division of the Naval Air Systems Command (NAVAIR) produced a set of life limits for the various components of the airframe. A summary of these airframe component life limits is in Table 3.1.

The E-2C fatigue test covered 30,703 test-spectrum flight hours. The structural life of the E-2C is determined in the traditional U.S. Navy fashion—it is basically set at one-half of the fatigue-test demonstrated life. However, various parts of the test airframe failed before the 30,703 test-spectrum flight hours point was reached and were modified or replaced. Thus, many parts of the airframe have shorter lives than other parts of the airframe. The overall life of the E-2C is about 10,000 hours, which is driven by the life limit of the wing center section (WCS) and the empennage. The outer wing panel (OWP)

Table 3.1

E-2C Airframe Fatigue Life Limits

Airframe Structure	Life Limit
Wing center section	11,450 flight hours
Nacelle	No established life limit
Fuselage	15,350 flight hours
Main landing gear	No established life limit
Nose landing gear	4,225 catapult launches
Outer wing panel	7,500 flight hours
Rotodome pylon	15,350 flight hours
Rotodome	No established life limit
Empennage	10,000 flight hours

[2]For an aircraft already at its maximum weight limit, carrying this much additional weight would require redesigning a critical section of the airframe, which would in turn would require the airframe to be requalified through costly and time-consuming tests. At the time of this study, the Navy had not fully assessed the impact of the weight increase.

is replaced at the 7,500-flight-hours point as part of the routine airframe maintenance. However, the fleet aircraft are retired much sooner than the 10,000-hour life limit as the newer and more-capable airframes are introduced.[3]

In terms of fatigue testing, the E-2C has the advantage of having a wing in common with the C-2A.[4] Subsequent to the E-2C fatigue test, the C-2A also underwent a similar test program and many of the findings in the C-2A testing apply directly to the E-2C. Additionally, the C-2A program also included performing a thermal test of the OWP, the results of which have already been used to establish the life of the OWP on the E-2C.

ADDING COOPERATIVE ENGAGEMENT CAPABILITY TO THE E-2C FLEET

Table 3.2 lists the equipment being retained from the current fleet of E-2Cs and the new equipment being incorporated into the E-2C

Table 3.2

CEC Equipment Being Retained or Incorporated into the Group II E-2Cs

Retained	Incorporated
APS-145 radar system	New mission computer— Data loader/recorder
Improved IFF system	Advanced control indicator suite workstations
Communications suite with joint tactical information distribution system	Satellite communications (with ARC-210)
Global positioning system	Vapor cycle upgrade
Dual Carrier Aligned Inertial Navigation System II (CAINS II) navigation[a]	Cooperative engagement capability
Automated flight control system upgrade[a]	Electronic support measures upgrade
	Producibility/reliability and maintenance initiatives

[a]Aircraft with Group II navigation systems upgrade.

[3]The average life of an E-2C retired from January 1973 to March 1992 was about 6,800 flight hours, excluding lost hours due to crashes and hours spent in storage.

[4]The C-2A Greyhound is a carrier-capable twin-engine aircraft designed to provide critical logistics support.

HE2000 configuration that was scheduled for delivery in October 2001. The airborne CEC technology, designed in the mid-1990s, can be incorporated during new production or retrofitted to existing aircraft.

As stated earlier in this report, NGC is currently under a multiyear contract to deliver 21 E-2Cs with the HE2000 configuration. This configuration builds on the MCU configuration by adding satellite communication (SATCOM) and CEC capability. NGC has already retrofitted two existing aircraft with this capability. Because the CEC is in production and the retrofit capability already has been demonstrated, the cost issues and technical and scheduling challenges are deemed to be minimal.

AIRFRAME LIFE EXTENSION STRUCTURAL MODIFICATIONS

Although the implementation of the CEC mission suite has been demonstrated, the E-2C airframe has never gone through any life-extension modification. In this section, we address airframe life and the necessary modification work to extend that life.

The most common problems with aging airframes are fatigue and corrosion. Virtually all of the fatigue problems found during testing occur at fastener holes. To remedy this problem, the best approach is cold working[5] the fastener holes or installing interference-fit fasteners[6] or a combination of both. These enhancements are inexpensive and, if adequate, should be the first choice. If the cracks have grown too large to be repaired before they are discovered, the test article (an airframe designed and built for specific types of tests) may require additional reinforcements before the test is completed on the remainder of the airframe. These reinforcements should be as minimal as possible, unless they are to be installed on all fleet aircraft, be-

[5]Cold working is accomplished by using an oversize tapered mandrel prefitted with an internal stainless steel sleeve to reduce stress around the fastener holes. The primary effect of cold working is to reduce the rates at which cracks grow.

[6]These fasteners have a larger dimension than the hole into which they are placed. Their purpose is to increase fatigue life.

cause the local area where the fatigue is worst will not be representative of the same area on the remainder of the fleet.

If fatigue cracks are discovered in areas other than holes, the only inexpensive option is *blending*—reducing the local stress concentration through *shot peening* or *laser peening*.[7] This process is less effective than cold working or *force-mating*[8] interference-fit fasteners into structural components, but is much more economical than bolt-on reinforcement or complete replacement of the part.[9]

In the following sections, we review each of the major parts of the E-2C airframe and the NAVAIR recommended life-extension structural modifications.

Wing Center Section

The wing center section was tested to 22,989 test spectrum hours (TSH) and is currently limited to 11,450 flight hours. Following the fatigue test, a teardown of the WCS was performed with all the crack findings documented and evaluated. The life of the WCS was established except for two areas that still need further work. Those areas are the lower skin/aft hilt fitting and the main beam web. They need further analysis to establish when the cracks in them occurred. To achieve the current life limit of 11,450 TSH, the following three areas require modification:

- *Lower skin/aft hilt fitting.* This is a simple and inexpensive modification that involves cold-working some holes.
- *Main beam web.* Cold-working of some holes is required.

[7]Shot peening is a cold-working process used to extend the fatigue life of metal parts. The parts are bombarded with round steel, glass, or ceramic shot under controlled conditions. The laser peening process is also called *laser shock peening* and is used to reduce metal fatigue.

[8]In this process, a bushing is inserted into a lug, and a mandrel is pushed through the bushing causing expansion of the bushing and lug. This in turn increases the fatigue life of the lug.

[9]In recent years, there has been a considerable amount of development on and some application of bonded composite doublers. These doublers are essentially added materials that are bolted or bonded to the parent structure to reduce local stress or to repair damage.

- *WCS closure rib sealant groove.* Repair to this area involves bolting on two bathtub fittings that were developed when the same sort of crack was noted in the C-2 fatigue test.

Nacelle

The nacelle (engine casing) currently has no established life limit. However, it does have two time compliance requirements (TCRs) that were established based on the C-2 fatigue test. The required changes involve replacing the crossbeam and the isolator fittings.

Fuselage

The fuselage was tested to 30,703 TSH and is currently limited to 15,350 TSH. The principal finding revealed approximately 150 fuselage skin cracks. These cracks are thought to be due to the manner in which the dynamic high-sink-speed landing loads were developed into test loads and how they were applied to the test article.

Two other areas, however, require modification to achieve the current fuselage life limit of 15,350 TSH—the main escape hatch (MEH) area, where cracks were noted at 28,500 TSH, and the longeron, where there were some cracks, which will require only cold working.

Landing Gear

There are two types of landing gears in the E-2C: the main landing gear located under the wings and the nose landing gear located in the forward section of the fuselage.

Main Landing Gear. The main gear was not tested as part of the full-scale fatigue test and no finite life for it has been established. Service experience to date has not found any fatigue problems with the gear because no cracks have ever been found. The only problem has been corrosion, which is cleaned up with surface material removal.

Nose Landing Gear. The nose gear was tested as part of the full-scale fatigue test and experienced no cracking throughout the full test of 30,703 TSH, which included 8,470 catapult launches. The current life

limit for the nose gear as established by the test is 4,225 catapult launches.

Outer Wing Panel

The OWP was tested in the full-scale fatigue test and was initially found to have a life of 5,200 TSH. However, additional testing of a modified OWP raised the life to 7,500 TSH. During the period following the E-2C tests, which were conducted from 1985 until 1993 and prompted by findings during the teardown of fleet C-2 OWPs, it was discovered that the life of the OWP is adversely affected by the heat from the engine tail pipes when the wing is folded. This led to a thermal survey of an E-2C aircraft at the Navy's Patuxent River, Maryland, facility, which provided extensive information on the extent of the problem.

It was subsequently decided that a thermal fatigue test of the OWP should be performed, which concluded only recently. This test ran a total of 20,000 TSH using a C-2 usage spectrum. The actual life limit of the OWP was determined by this test; however, the limit has not yet been established because the crack regression work to determine when the cracks that were found in the OWP thermal test had developed has yet to be performed.

Rotodome Pylon

The rotodome pylon was tested for 30,703 TSH. This test included 37,837 landings and 8,470 catapult launches. The teardown of this structure has been completed and only cracks in the fairings were noted, with no defects in the primary structure. The life of the rotodome pylon is therefore set at one-half of its test life, or approximately 15,350 hours.

Rotodome

The rotodome was not tested during the E-2C full-scale fatigue test. This is a largely composite part and therefore is relatively immune to fatigue. Rotodome structures are proof tested following initial production and have not shown any problems in the fleet. Hence, this structure has no life limit.

Empennage (Tail Section)

The empennage was tested as part of the E-2C full-scale fatigue test; however, the test was originally intended as a means of applying accurate loads to the aft fuselage. At 13,670 TSH, the forward horizontal-to-fuselage attach fittings failed. A subsequent investigation revealed that these parts had been tested and were redesigned and replaced on fleet aircraft, so this failure does not currently represent any life limit. Cracks were found in the access cutouts in the horizontal tail upper skin and the discovery of those cracks has resulted in a life limit of 10,000 hours for the empennage. This limit seems to be simply the contractual life of the aircraft.

LITTORAL CAPABILITIES AND THE RADAR MODERNIZATION PROGRAM

The Navy anticipates that the mission of the E-2C will evolve from solely blue-water operations to also include operations in littoral and overland environments. Simultaneously, the threat of hostile forces has become a much larger challenge to the AEW system. Small cross-section theater missiles along with intense electronic jamming are significant threats that must be addressed.

The current E-2C APS-145 AEW radar technology offers significant capabilities against conventional threats in moderate jamming scenarios. Expanded capabilities will be required, however, to deal with emerging threats in the littoral and overland environments.

The main thrust of the littoral program is the development of a new AEW radar system. Technologies required for this new AEW radar include an electronic beam steering antenna, a solid-state transmitter, a high-gain receiver, and space-time adaptive processing (STAP). The main focus of this development program is upgrading the radar, but other key avionics systems are also being redesigned. In fact, the Navy has budgeted about $880 million for the development of RMP. The current Navy development program is geared toward reducing the risk of radar failure by addressing:

- The radar's weight and size
- Cooling of the radar transmitter

- Hot clutter[10] and high-power wide-band jamming
- Signal processing required in the littoral environment.

The Navy has an extensive program to address the risk areas in the E-2C RMP program but has not yet addressed the airframe issues caused by the radar modernization program in any detail.

Table 3.3 lists the avionics suite of the E-2C with CEC capability and the E-2C with RMP capability.[11] The RMP avionics suite will add about 2,500 pounds to the 55,000-pound E-2C.

The 2,500-pound weight increase from the avionics suite poses a significant challenge in airframe design and modification because the current E-2C airframe is already near its weight threshold of 55,000 pounds. Any increase would also boost the load and stress levels applied to the airframe structure and could require a redesign of major portions of the airframe. This redesign would likely require a costly series of airframe certification tests, including full-scale static,

Table 3.3

CEC and RMP Avionics Suite

CEC Capability	RMP Capability (Additions to the CEC)
CEC system (AN/USQ-3A)	Advanced radar and IFF subsystems
Electronic support measurement system (AN/ALQ-217)	Mission computer upgrade
Joint Tactical Information Distribution System communications	Communications upgrade
CAINS II navigation/Global positioning system	Tactical cockpit
T56-A–427 engines	Generator upgrade
NP2000 propellers	Producibility/reliability and maintainability/readiness initiatives

NOTES: The configuration upgrade is based on information provided by NGC. The specifics on technologies being retained or incorporated will be the topic of the Navy's RMP development contract, which has yet to be awarded.

[10] *Hot clutter* refers to manmade objects that have high radio frequency reflectivity (that is, objects that preferentially scatter a noticeable portion of the transmitter beam back at the transmitter).

[11] An E-2C with littoral capability is also known as an "RMP-capable E-2C."

fatigue, and drop testing plus structural flight testing. This higher weight would also require a re-evaluation of the aircraft's performance, such as its performance in flight and carrier suitability.

Modifying the airframe in order to accommodate the new avionics suite can also have significant scheduling and cost implications. The additional weight may also reduce the current airframe life prediction to somewhat less than 10,000 hours. The airframe modification to accommodate the RMP avionics in the existing fleet is significantly more challenging than the CEC upgrade discussed earlier in this chapter. Discussions with NGC and NAVAIR indicate that they both believe the entire fuselage would have to be disassembled in order to replace and strengthen key structural components, such as the longerons and the bulkheads (the gray details in Figure 3.1 illustrate areas of the aircraft that would be modified in this way). This disassembly, reassembly, and modification process is as involved as building an entirely new fuselage.

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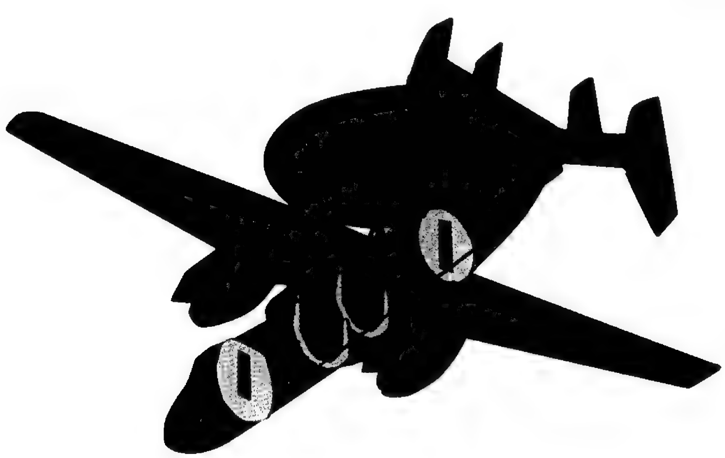

Figure 3.1—Sections of Aircraft Modified to Accommodate RMP Avionics

OVERALL ASSESSMENT OF THE UPGRADE PROGRAMS

The technologies required for the CEC program are mature and therefore their incorporation into the existing E-2C aircraft poses few risks in terms of cost and time schedules. Conversely, the technologies required for the RMP program are far less mature. Table 3.4 summarizes our assessment of the maturity of the airframe and avionics for the two modernization programs. The assessment is based on the following criteria:

- High Maturity: Minimal development and minimal nonrecurring costs are required.
- Moderate Maturity: Further maturation of the technology is required. Development requirements and nonrecurring costs are identified.
- Low Maturity: Significant further development and significant nonrecurring costs are required. Total required costs are not yet determined.

Of the technological areas that we assessed, those related to the RMP avionics are regarded as having moderate maturity and those for the airframe are regarded as having low maturity.

Table 3.4

Assessment of the Technology Maturity Levels

Upgrade Program	Avionics	Airframe
CEC	High	High
RMP	Moderate	Low

Chapter Four

E-2C AIRCRAFT INVENTORY AND SCHEDULING ANALYSIS

Any cost-benefit assessment requires clear establishment of the advantages of a particular program or course of action. In this chapter, we assess the benefits of a structural life extension program and modification (SLEP/MOD) program for the E-2C fleet with respect to aircraft inventory. Clearly, one of the possible benefits of undertaking such a program is that the useful life of the existing fleet would increase, reducing the need to buy new aircraft in order to maintain the E-2C inventory. A combined SLEP/MOD program would also improve the capabilities of the current fleet. These advantages must be weighed against having to remove aircraft from active service during the period that the work is completed.

As we go through our analysis of aircraft inventory for the E-2C fleet, we compare the number of operationally available aircraft (those that can be assigned to a squadron) to the PAA level under different scenarios.[1] If general force levels in the Navy were to change, particularly the number of aircraft carriers, then some different PAA value would be appropriate.

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[1]There is one fleet requirement we should mention: Individual squadrons must be equipped with the same configuration of E-2C aircraft. This practice is done not only to simplify maintenance of the aircraft but also to reduce the training and workload burdens on aircrews. It is far easier for a crew to fly the same configuration of an aircraft during a deployment. However, we do not address this additional configuration constraint in the force-size analysis because it is beyond the scope of this study. The results we present should be considered a "best case" situation. We make no judgment on the correctness or appropriateness of the minimum of 63 PAA aircraft the Navy needs to meet its operational requirements.

CURRENT FLEET DATA

To assess how a SLEP/MOD program might affect aircraft inventory, we need to establish the composition of the fleet, the various ages of the aircraft, and how the aircraft are used. The E-2C program office, PMA-231, tracks the status, usage, and configuration of every E-2C aircraft. The office provided RAND with a summary of the E-2C fleet as of December 2000. The data in the summary contained information on configurations, locations, total flight hours, total landings, new aircraft delivery dates, and expected retirement dates. We supplemented this data with the established delivery plan for the current multiyear contract. These data formed the baseline for our study on inventory levels.

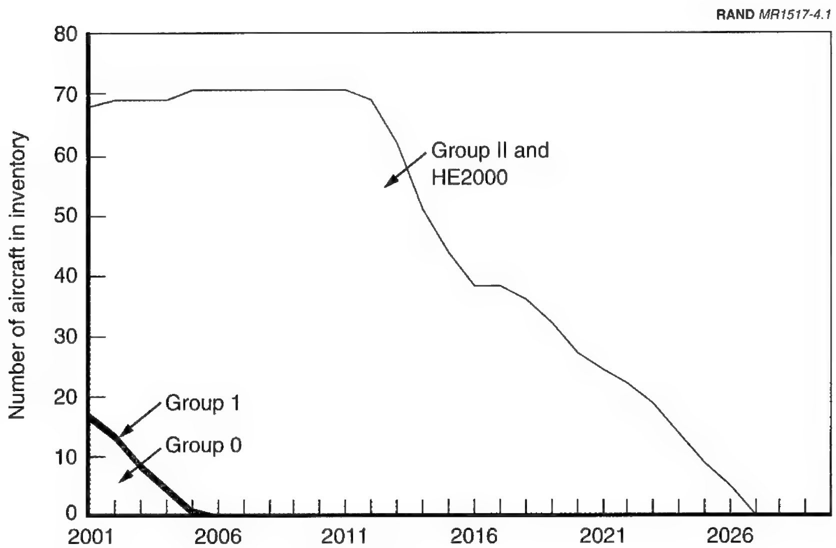
Figure 4.1 projects the E-2C aircraft inventory over the next 30 years by configuration. In plotting the figure, we assumed that the Group 0 and Group I aircraft will retire as soon as the multiyear production is delivered. As noted in Chapter One, the multiyear contract calls for 21 new aircraft, with the last to be delivered in 2006.[2]

More important than the total aircraft inventory is the number of aircraft that can be assigned to the operational, training, and RDT&E squadrons. An aircraft undergoing repair or modification is of little use to a warfighter. In this vein, we assess not only the total aircraft inventory but also the available aircraft to meet the PAA requirements. The underlying question we seek to answer is whether there are enough available aircraft to meet the operational, training, and RDT&E needs.

FACTORS AFFECTING AIRCRAFT AVAILABILITY

To determine the number of available aircraft under various SLEP/MOD scenarios, we first need to take into account when various activities occur during the life of an aircraft (for example, when aircraft undergo depot work, when they are retired, when they are

[2]During our analysis, there was a congressional "plus-up" to modify one of the Group I aircraft to an HE2000 aircraft. Our analysis does not reflect this modification.



NOTE: Group I is RDT&E aircraft.

Figure 4.1—E-2C Inventory Projection

modified, and so forth). For the inventory-level analysis, RAND developed a constrained scheduling model. The model determines, on a monthly basis, whether a particular aircraft is available. Several factors could cause an aircraft to become unavailable:

- *Retirement.* When an aircraft reaches its flight hour limit, it is retired from the fleet.
- *In storage or inactive.* There are two specific situations in which these conditions would apply. The first occurs when an aircraft is considered to be either in reserve storage or on hold for foreign military sales. That aircraft will have been removed indefinitely from the active fleet. The second situation occurs when an aircraft has reached its initial life limit (10,000 hours) and is awaiting SLEP/MOD work. Such an aircraft is considered inactive until the SLEP/MOD is complete.
- *SLEP/MOD.* An aircraft undergoing a SLEP/MOD is not available to the operational units.

- *Programmed depot maintenance.* An E-2C undergoes depot maintenance on a regular basis. During this maintenance period, the aircraft is inactive. Each E-2C has a regular PDM schedule. The aircraft is active for 40 months, after which time it undergoes depot maintenance. The maintenance period is either two or five months, depending on the extent of the maintenance. The aircraft then returns to the fleet for another 40 months. This cycle repeats itself until the aircraft retires. Approximately 8 percent of the aircraft are in PDM at any given time.

- *Attrition.* Occasionally, aircraft are lost due to a mishap or some failure. Such incidents are unplanned but nonetheless reduce the overall aircraft inventory. We simplified the determination of the number of available aircraft in one important way with respect to attrition of aircraft. Because attrition is a random occurrence, we cannot know which particular aircraft will be affected. To modify the active aircraft count, we applied a uniform annual attrition rate of 0.3 percent of the total aircraft inventory per year after all other factors have been addressed.[3] Only active aircraft are removed from the count. However, because attrition is a random event, the SLEP/MOD and PDM schedules are assumed to be *unchanged.*

The inventory of available aircraft can increase only if new production exceeds the losses. As the multiyear production proceeds, new aircraft are introduced into the fleet on a regular basis through 2006 with one new aircraft delivered every three months.

CURRENT AIRCRAFT INVENTORY

Using the model described in the previous sections, we can forecast the number of available E-2C aircraft minus any SLEP/MOD program. The forecast is shown in Figure 4.2. The two horizontal lines at the top of the chart represent the established PAA and TAAI levels, which are 63 and 75 aircraft, respectively. We have assumed that

[3]The 0.3 percent attrition rate is the official rate for the E-2C. It is equivalent to about one aircraft every three to four years and is based on the information provided by NAVAIR 4.3.

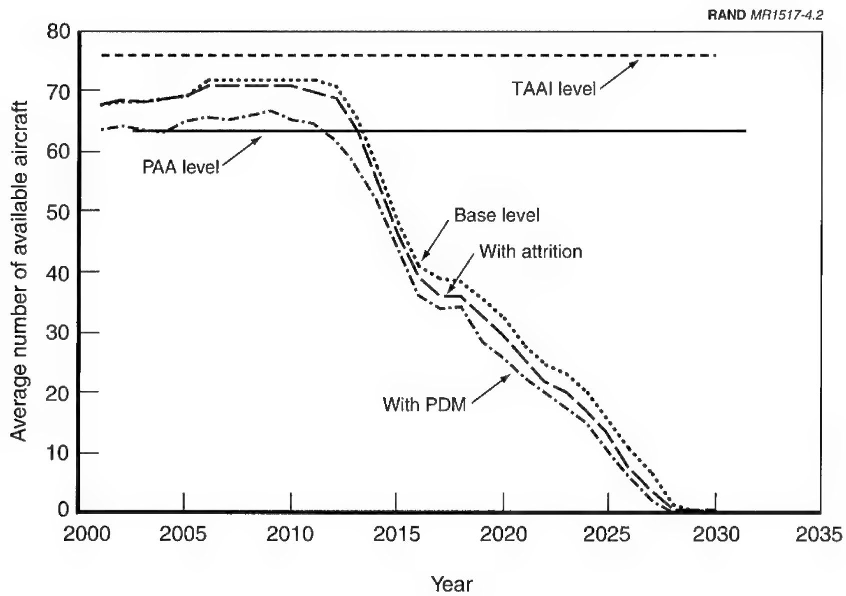


Figure 4.2—Projection of E-2C Inventory Levels Without the SLEP/MOD Program

these levels will not change over the 30-year interval depicted in the figure.

The topmost curved line ("Base") in Figure 4.2 shows the total number of aircraft, taking only retirement into account. It is equivalent to the "Group II and HE2000s" inventory line shown in Figure 4.1. The middle curved line ("With attrition") shows the effect of attrition on the baseline inventory. The curved line at the bottom ("With PDM") shows the average number of available aircraft after accounting for both attrition and PDM. This level is what we consider to be the number of available aircraft to meet the 63 PAA requirement. Notice that this number hovers around the PAA requirement level until 2011. After that time, the forecasted number of available aircraft falls permanently below the PAA level. Another important point about Figure 4.2 is that the "With PDM" line falls below the PAA requirement line about three years sooner than the "Base" line does.

In other words, the simple analysis depicted in Figure 4.1 actually overstates the number of available aircraft.

SLEP/MOD SCHEDULE CONSTRAINTS AND ASSUMPTIONS

The scheduling model we have discussed introduces a series of constraints with respect to the SLEP/MOD schedule. Those constraints limit when certain activities can occur. For all the options we analyzed, we have assumed that one facility—NGC's Saint Augustine location—will do all the SLEP/MOD work. The constraints are as follows:

- *Limits on the number of aircraft simultaneously*[4] *undergoing SLEP/MOD.* The number of aircraft that can undergo SLEP/MOD work simultaneously is determined by a facility's throughput limit. For example, a throughput limit of four aircraft means that only four E-2Cs can be worked on at once.
- *Start intervals.* The SLEP/MOD work has to be reasonably spaced out to ensure a level workload at the facility. Several aircraft cannot enter the life extension or modification process at the same time because the facility needs to distribute its labor force for optimum efficiency and stable employment.
- *Minimum flight hours for SLEP/MOD.* The aircraft must have reached a minimum number of flight hours before undergoing the SLEP/MOD process. For the analysis that appears later in this chapter, we assume that the minimum is 8,000 flight hours.[5]
- *Availability of technology (RMP only).* Some technology required for the modification portion of the work won't be available until sometime after 2006. This constraint applies only to the RMP modification. We have assumed that the first RMP modification could begin in June 2007.

[4]In this chapter, "simultaneous" SLEP/MOD work on multiple aircraft refers to SLEP/MODs that overlap but do not necessarily start and stop at the same time.

[5]We selected 8,000 flight hours as the earliest start for SLEP because it corresponded to our goal time—15,000 hours minus the life of the outer wing panels, which is approximately 7,000 hours. By selecting 8,000 hours as the minimum, it should make it unnecessary to replace the outer wing panels before the new 15,000-hour limit.

- *SLEP/MOD work replacing a PDM.* The aircraft will skip the PDM closest to the SLEP/MOD work. The SLEP/MOD activity will therefore include the necessary maintenance, adding more work and keeping the airplane out of service for a longer period of time.

The following assumptions are also taken into account in our estimations of available aircraft:

- Only the Group II and HE2000 aircraft (through the end of the multiyear production with aircraft number A199, the last to be delivered under the multiyear contract) would undergo a SLEP/MOD.
- The SLEP activities extend the total life of the aircraft to 15,000 hours by adding an additional 5,000 hours of useful airframe life (independent of when the SLEP occurs after the required 8,000 flight hours before SLEP/MOD).[6] The base life of the E-2C (as it is produced) is 10,000 flight hours.
- Each aircraft accumulates an average of 37.2 flight hours per month when active.

The inactive period for the aircraft during SLEP/MOD activities is from the point the aircraft in inducted to the point the government accepts the modified aircraft. The inactive-aircraft time periods are as follows:

- 24 months for RMP
- 18 months for HE2000 upgrade of existing Group II aircraft
- 12 months for SLEP only if the aircraft is an HE2000 configuration.

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[6]We assume that the number of hours added to the life of the aircraft is independent of the modification upgrade (RMP or HE2000). In the cost analysis in Chapter Five, we state that for the RMP upgrade, the fuselage will be significantly modified or replaced. However, given the 2,500 pounds of weight the RMP adds and the fact that other airframe components might be life limiting, it is far from certain that more than 15,000 hours of total life could be achieved. We have erred on the conservative side for the RMP SLEP/MOD.

IMPACT OF SCHEDULING ON INDUSTRIAL BASE AND AIRCRAFT INVENTORY

The timing and scheduling of the SLEP/MOD program is an important issue to address because of its impact on the industrial base. Some questions that we need to ask in this regard are:

- How are workloads distributed across the facility?
- Can the facility meet the demand for the SLEP/MOD work?
- Will the workload be steady?

The timing of the program also affects the aircraft inventory, and raises further questions:

- Can the program keep pace with the aging inventory (that is, are aircraft reaching their initial life limit before reaching the SLEP/MOD event)?
- When are aircraft unavailable for use as active aircraft?

To illustrate how timing affects the impact of SLEP/MOD activities, we begin with a simple example of SLEP/MOD activities. The only constraint we apply is that each aircraft must have accumulated at least 8,000 flight hours before being inducted. Figure 4.3 shows the notional induction flow of E-2C aircraft given such a constraint. Each bar in the chart represents the SLEP/MOD of an individual aircraft by tail number.

In this situation, it takes approximately 17 years to SLEP/MOD all the aircraft. None of the aircraft reach 10,000 flight hours before being inducted. However, the schedule is not practical from an industrial base perspective. The number of overlapping SLEP/MODs varies considerably. In the early years through 2011, the simultaneous work exceeds the notional NGC–Saint Augustine capacity of eight aircraft[7] undergoing SLEP/MOD at any one time, which rapidly falls to just a couple of aircraft between 2012 and 2014 and rises again by the end of 2014.

[7]This number represents the current NGC–Saint Augustine tooling and facility limitations.

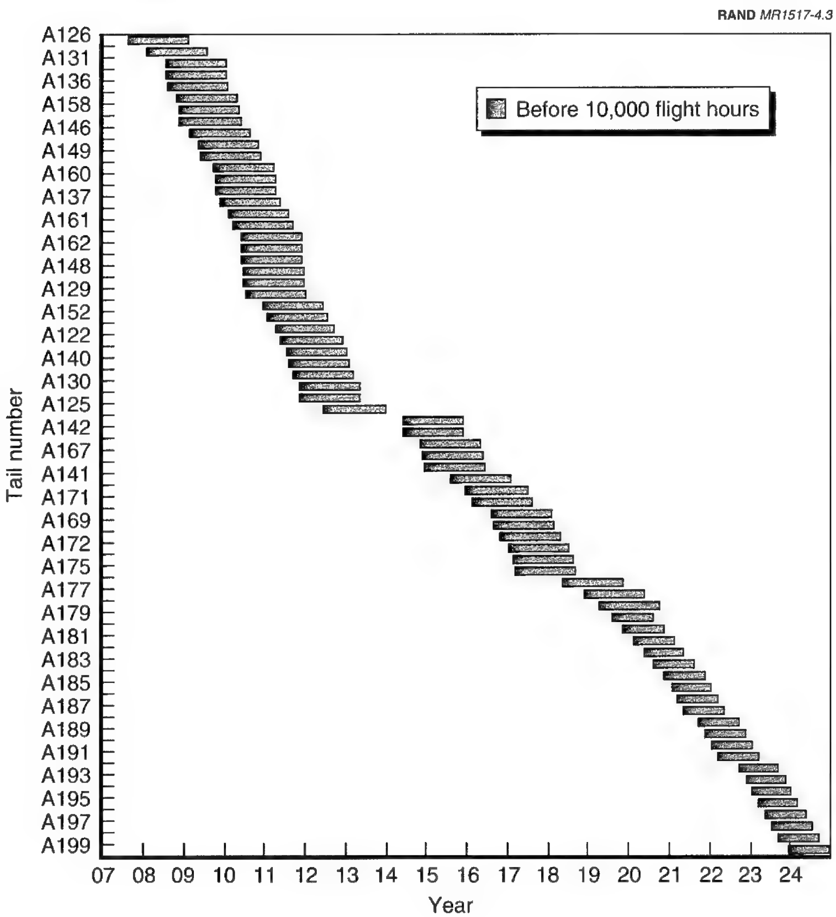

Figure 4.3—Flow of Aircraft into a SLEP/MOD Program with No Industrial Base Constraints

If we limit the amount of simultaneous activity to no more than four aircraft inducted at any one time, the schedule that would result is the one depicted in Figure 4.4. The overall program would in this case take about 25 years to complete. However, there is a backlog of work by 2015 (this is shown by the "After 10,000 flight hours" bars in the figure). The NGC–Saint Augustine facility cannot keep up with

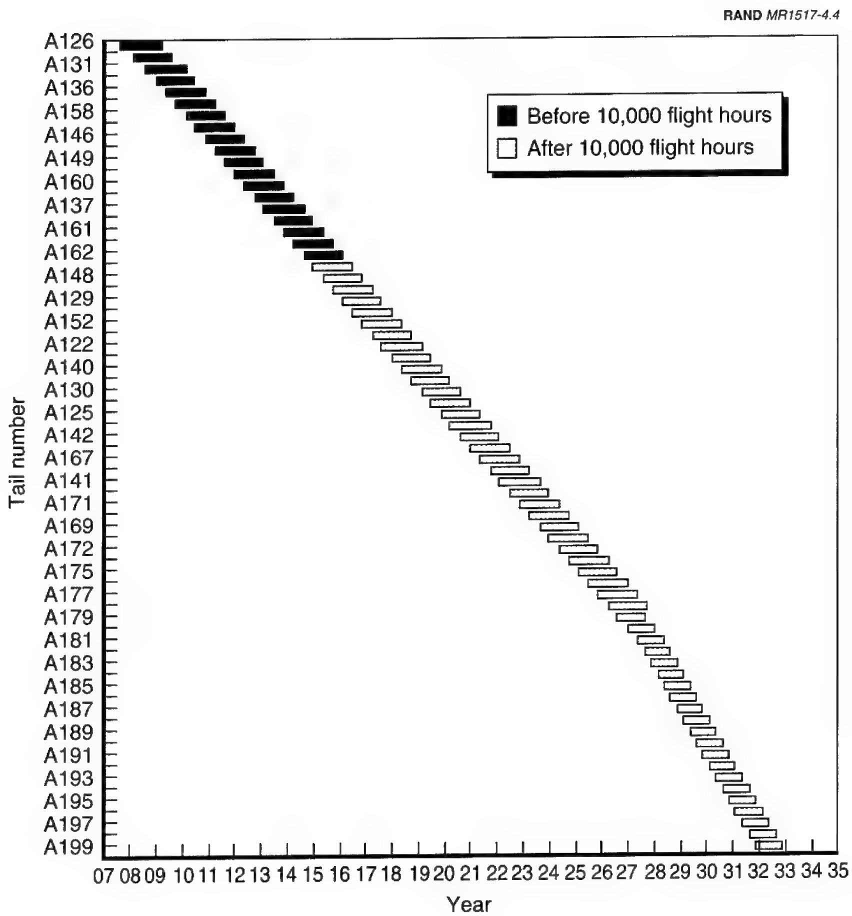

Figure 4.4—SLEP/MOD Activity Schedule with a Limit of Four Inducted Aircraft per Year

the aircraft reaching the 10,000-hour limit. Therefore, these aircraft must be placed in inactive status awaiting induction.

Figure 4.5 shows the variation in the SLEP/MOD total program duration in years given differing numbers of aircraft in SLEP/MOD at any one time. The program duration falls sharply between two and four simultaneous SLEP/MODs. Beyond five simultaneous SLEP/MODs, the total program duration is not shortened appreciably because the

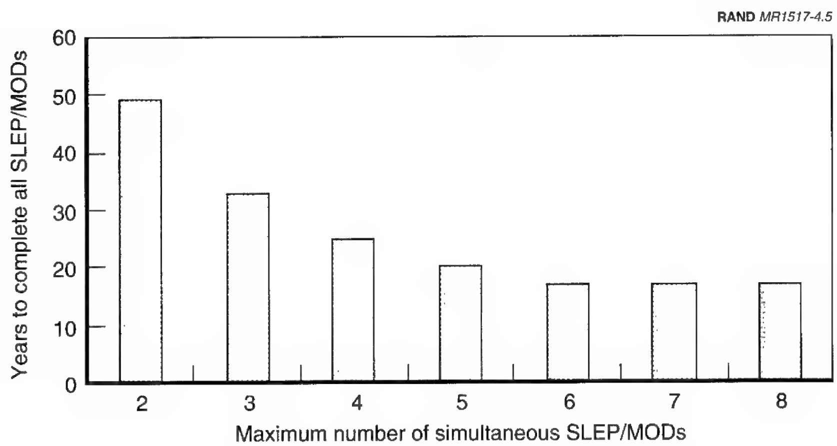

Figure 4.5—Effect of Simultaneous Work Loads on SLEP/MOD Program Duration

duration is limited by the number of aircraft reaching 8,000 flight hours rather than by facility throughput.

EFFECT OF THE SLEP/MOD PROGRAM ON OPERATIONALLY AVAILABLE AIRCRAFT

One of the potential benefits of a SLEP/MOD program is to extend the life of the E-2C fleet, thereby maintaining aircraft inventory beyond the currently forecasted levels. This raises a question: To what extent does the SLEP/MOD program improve the aircraft inventory?

Figure 4.6 shows the number of operationally available aircraft for three different scenarios. The "Current fleet" line reflects a forecast of the current fleet without any SLEP/MOD activity with each aircraft retired at 10,000 flight hours and new aircraft procured after the current multiyear contract. The "With HE2000 configuration and four simultaneous SLEP/MODs" and "With HE2000 configuration and eight simultaneous SLEP/MODs" lines plot the number of active aircraft when there are no more than four or eight simultaneous SLEP/MODs. Both lines represent SLEP/MODs being done to the HE2000 configuration. Notice that until 2011 the Current fleet scenario keeps the fleet at higher levels relative to the PAA requirement

as compared with the SLEP/MOD scenarios. In fact, both of the SLEP/MOD scenarios result in fleet levels falling below the PAA requirement five years sooner than they do in the Current fleet scenario. This earlier drop occurs because SLEP/MOD induction reduces the available aircraft.

Because the actual E-2C inventory is below the TAAI of 75 aircraft, there is not enough slack in the inventory to accommodate even as few as four aircraft out of the fleet for SLEP/MOD while also accounting for attrition and PDM. It is also interesting to note that after 2015 the number of available aircraft in the four-simultaneous-SLEP/MODs scenario falls significantly below that for the eight-simultaneous-SLEP/MODs scenario. This gap is primarily due to the backlog of aircraft awaiting the SLEP/MOD process (see Figure 4.4, which shows the number of aircraft beyond 2015 that have met the 10,000 hours of service life and are awaiting SLEP/MOD).

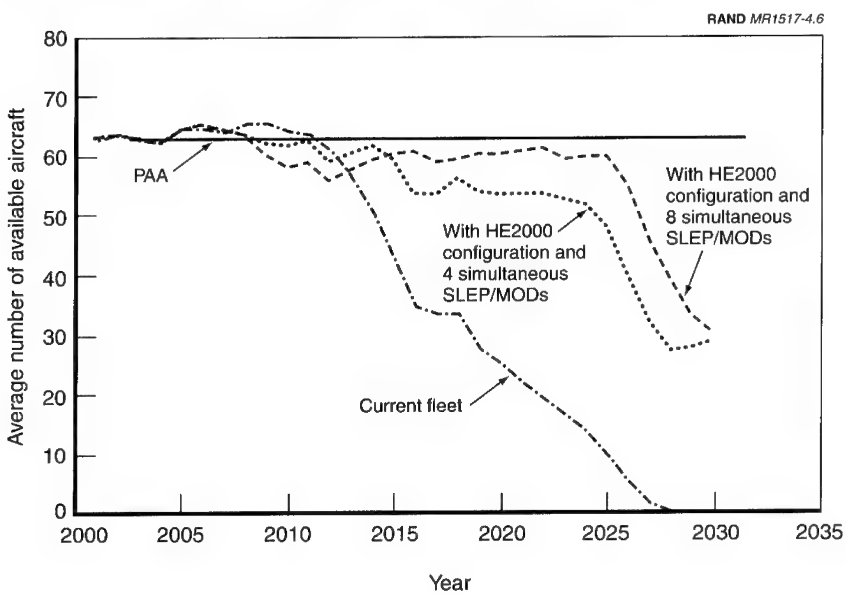

Figure 4.6 —Number of Available E-2C Aircraft Given Different Program Scenarios

The number of operationally available aircraft does not change appreciably if the modification is to an RMP configuration rather than to an HE2000 configuration. Figure 4.7 compares an HE2000 modification with an RMP modification. The Current fleet scenario keeps the fleet at higher levels relative to the PAA requirement when compared with either of the other scenarios. In fact, both the HE2000 and RMP SLEP/MOD scenarios result in fleet levels falling below the PAA requirement five years sooner than they do in the Current fleet scenario.

The SLEP/MOD program offers one notable potential benefit—the SLEP/MOD program upgrades the aircraft inventory to the newest configuration. If we look only at the number of CEC aircraft in the inventory over time, a SLEP/MOD program continues to increase the number of CEC-capable aircraft after the multiyear production ends (see Figure 4.8). The current fleet is limited to just those CEC aircraft

RAND MR1517-4.7

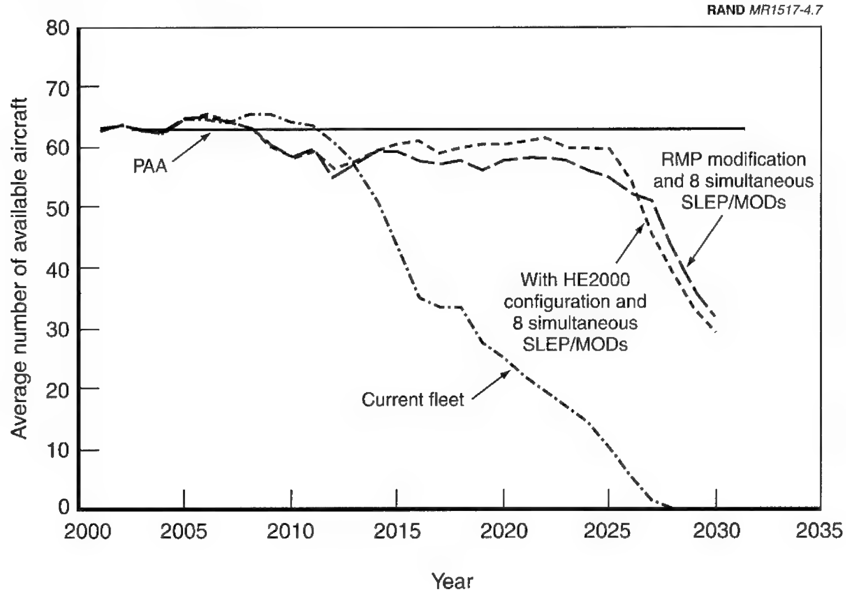

Figure 4.7—Comparison of the Number of Available E-2C Aircraft in HE2000 and RMP Modification Scenarios

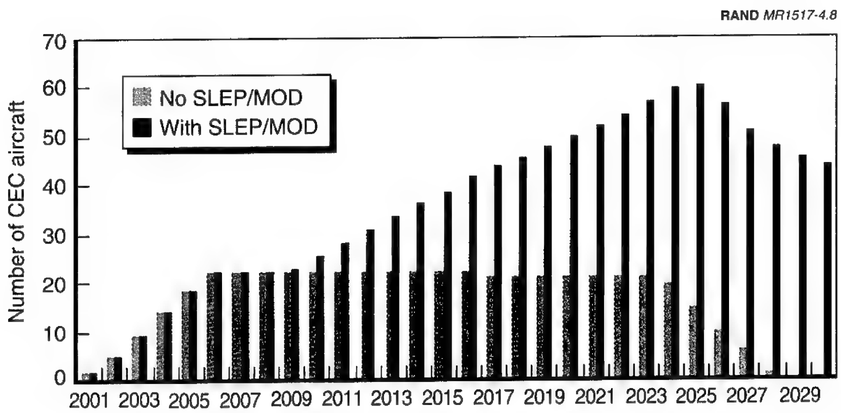

Figure 4.8—Number of CEC-Capable Aircraft in Inventory with and Without SLEP/MOD (maximum four simultaneous SLEP/MODs)

produced in the multiyear procurement (21 aircraft) plus the two modified aircraft. Of course, continuing new aircraft production after the multiyear contract would yield a similar result.

Would starting the SLEP/MOD program earlier be beneficial? Figure 4.9 shows the effects of starting SLEP/MOD work in 2004,[8] disregarding the constraint that an aircraft must reach 8,000 flight hours before entering a SLEP/MOD. In this case, the available aircraft levels for both the four- and eight-simultaneous-modifications scenarios fall slightly below the PAA level. In fact, the available aircraft levels in the eight-simultaneous-modifications scenario exceed the PAA requirement after 2015. Similarly, the scenario with four simultaneous SLEP/MODs results in available aircraft levels of approximately 60 until 2025.

It is not clear if starting the SLEP/MOD activities before the first aircraft reaches 8,000 flight hours is a viable approach for the Navy to extend aircraft inventory. First, the available aircraft levels never reach the PAA requirement of 63 aircraft. If the PAA requirement had

[8]We are assuming that this is the earliest possible date that a SLEP/MOD design package could be completed. At present, no SLEP/MOD package exists.

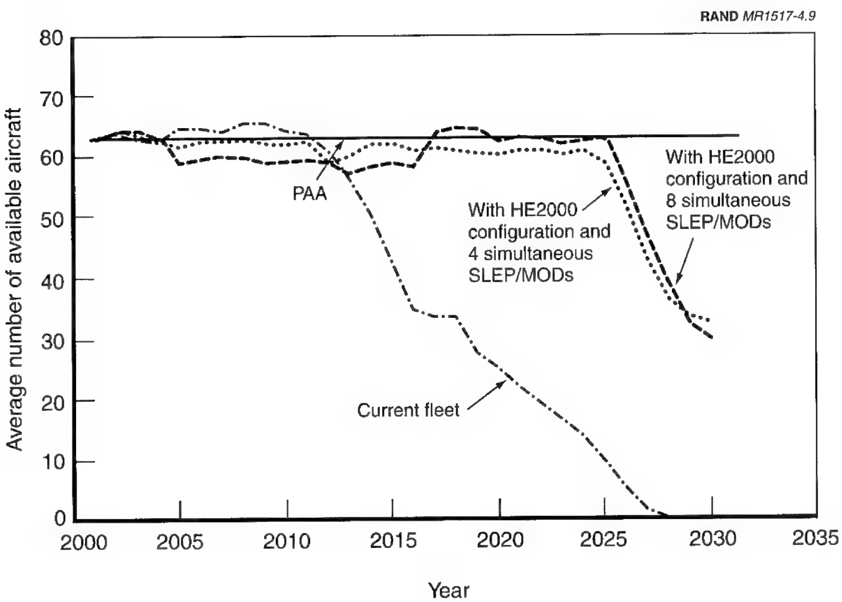

Figure 4.9—Number of Available E-2C Aircraft Given an Earlier SLEP/MOD Start

some flexibility, performing SLEP/MODs at a rate of four aircraft at once might be feasible.

However, there are two additional considerations. We have assumed an average and uniform attrition rate of one aircraft being lost every three to four years. If the attrition rate were slightly worse than average, the Navy might not have enough aircraft to meet its needs. Furthermore, the configuration of aircraft within each U.S. Navy and Navy Reserve squadron needs to be identical. That is, aircraft configurations cannot be mixed within a single squadron. For example, a Navy squadron cannot be made up of two HE2000 and two Group 0 aircraft. Therefore, simply having available aircraft at the PAA level does not necessarily guarantee that all squadrons can be outfitted properly.

ADDING NEW PRODUCTION

In the previous section of this chapter, we demonstrated that a SLEP/MOD program alone is insufficient to maintain the number of available aircraft at or above the required PAA number. Therefore, some new production is necessary to augment a SLEP/MOD program. In Figure 4.10, we show three viable scenarios for a combination of new production and SLEP/MODs that maintain the number of available aircraft above the PAA threshold until 2025. Note that all the scenarios assume that new production continues after the multiyear contract, so there is no production break. In all cases, the available number of aircraft exceeds the PAA level. For a production rate of two new aircraft a year, the Navy could consider ending the SLEP program sooner or retiring aircraft earlier once the number of available aircraft meets the TAAI level of 75.

An alternative approach would be to continue new production without any SLEP/MOD activity. Figure 4.11 shows the number of avail-

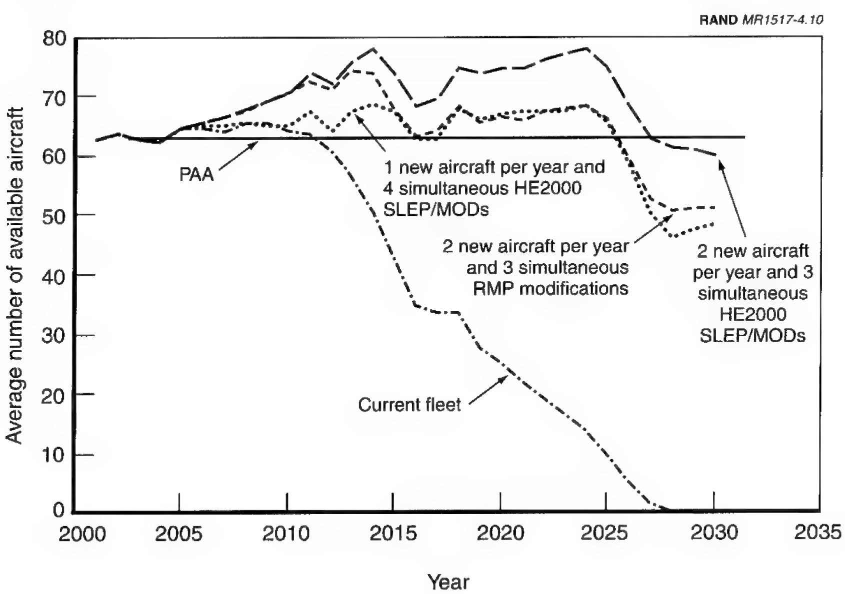

Figure 4.10—Number of Available E-2C Aircraft if SLEP/MOD Is Combined with New Production

able aircraft if production continues at a rate of four new aircraft per year. The figure shows that 2009 is the latest date production can restart after the multiyear contract. Of course, restarting production after a five-year production gap would be very difficult.

CONCLUSIONS

In this chapter, we examined the effect of the SLEP/MOD program on the E-2C available aircraft inventory. We find that a SLEP/MOD program alone does not keep the available aircraft level above the PAA requirement. Nor does starting a SLEP/MOD program as soon as possible maintain the available inventory at or above 63 aircraft, although with an early start, the inventory nearly maintains that level. Therefore, some new production is required. We find that at least one or two new aircraft per year would be necessary to meet the PAA requirement. Finally, one benefit of a SLEP/MOD program is that it helps to update the fleet by adding CEC capability.

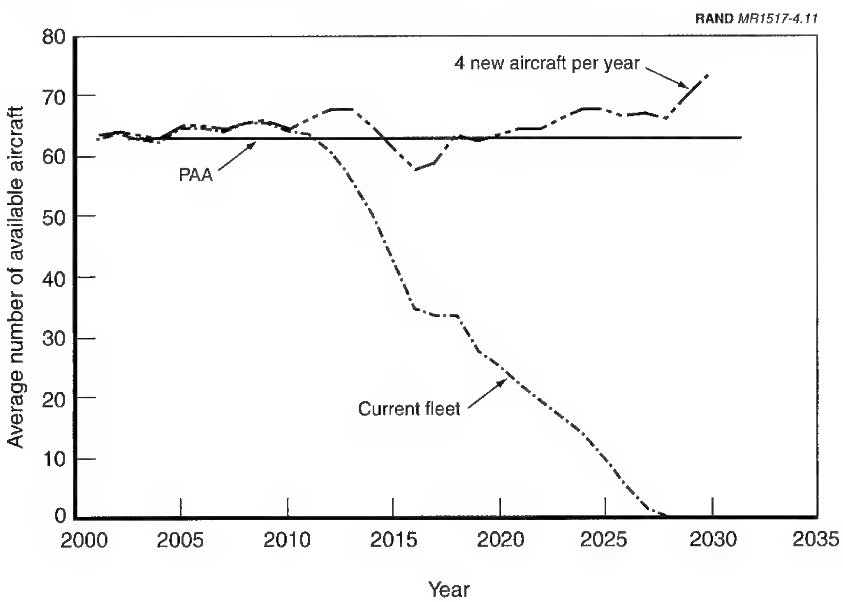

Figure 4.11—Number of Available E-2C Aircraft if New Production Is Restarted in 2009

Chapter Five

COST ANALYSIS

Our cost analysis of the E-2C program alternatives the Navy might consider addresses two main areas: acquisition costs, which include all costs associated with development and production, and the costs of operating, maintaining, and supporting the E-2C. The acquisition cost analysis in this chapter focuses on the cost impact from airframe life extension modifications and the mission suite upgrade required to convert Group II aircraft to aircraft with either CEC or RMP capability. The operations and support (O&S) analysis examines the implications for future E-2C O&S costs of developing a fleet of modified aircraft versus building new ones. We did not study the system design and development costs associated with the RMP.

This cost analysis is intended to provide a common basis of cost comparison among options; thus, we reduce costs to a common metric of dollars per flight hours of life. These figures should not be interpreted as budget costs.

ACQUISITION COSTS ANALYSIS

We considered two modifications to Group II E-2C configurations: the HE2000, which incorporates CEC technology, and E-2Cs that incorporate both CEC and RMP capability.[1] For both the CEC and RMP capability, the acquisition cost analysis includes service-life extension, including parts replacement, and retrofit for the performance-

[1]In this chapter, we use the terms CEC and RMP to refer to the HE2000 configuration and RMP configuration, respectively.

enhancement mission suite, which comprises modification, electronics, and installation. Also included in the analysis are system engineering and program management (SEPM) and retrofit support costs.

Detailed modification-cost estimates for the CEC analysis are based on actual costs of previous E-2C modification activities and were deemed to be thorough enough to be incorporated directly into this study. Modification costs for the RMP and SLEP costs were less certain and are subject to wide variances due to the differing perceptions the government and contractor personnel involved with the E-2C program have of the scope of the modification work. To account for these differing opinions, a range of costs was estimated. We anticipate that the final cost will tend toward the middle of the range.

SLEP and modification are not totally independent activities. For example, a new fuselage may be required for the RMP because it costs more to modify the old fuselage than it does to buy a new one. If properly designed for RMP loads and systems, that new fuselage would require no service-life extension actions. Therefore, we account for the new fuselage under modifications rather than as a SLEP cost. Therefore, the SLEP cost for the RMP is significantly less than that for CEC.

To simplify the data presented in this chapter, we have assumed that the nominal service life of a new-procurement aircraft is 10,000 hours, although some systems or structural parts may need to be replaced sooner and others may last longer than 10,000 hours. Similarly, the objective of the SLEP is to extend the airframe life another 5,000 hours, although individual parts or systems on the aircraft may last for longer or shorter periods of time. Costs and comparisons among alternatives are based on these assumptions of aircraft service life, without attempting to make definitive assessments of the life of each component part.

Pre-existing E-2C Program Configurations and Required Upgrades

A total of 47 Group II E-2C aircraft of various configurations are being considered for SLEP/MOD. Table 5.1 summarizes the major upgrade packages required by each group of aircraft to bring that group to

Table 5.1

Upgrade Packages Required to Bring E-2C Group II Aircraft to CEC Configuration

Upgrade Package	Basic	NAV	MCU
Navigation	X	N/A	N/A
Mission computer	X	X	N/A
CEC	X	X	X
Number of E-2Cs	23	18	6

CEC configuration. The aircraft are distinguished in the table primarily by the state of their navigation equipment (NAV) and their mission computer upgrade (MCU). For example, the NAV group of aircraft already has an updated navigation package installed and MCU aircraft already have the navigation package installed and the mission computer upgrades. Thus, the table indicates that only the Basic configuration group of the Group II aircraft requires the MCU and NAV packages.

The specifics of the upgrade to the RMP configuration for the 47 aircraft represented in Table 5.1 will be further defined as part of the future RMP system development and demonstration (SD&D) contract. In our cost analysis, we are erring on the conservative side, assuming that the RMP upgrade would involve replacing the existing radar, navigation equipment, and mission computer.[2] Thus, the cost to SLEP/MOD any Group II aircraft to RMP capability is the same as it is for any other Group II aircraft being upgraded to the RMP configuration, regardless of their preexisting capability.

Ground Rules and Assumptions for Acquisition Cost Study

The following ground rules and assumptions were used in the development and production cost analysis:

- All costs are in FY2000 dollars.

[2]The E-2C navigation system and mission computer may need to evolve due to parts obsolescence or performance requirements.

- Estimates are based on RAND research, NAVAIR (AIR 4.2),[3] and contractor information.
- The scope of the SLEP activity is based on discussions with NGC and NAVAIR (AIR 4.3.3[4] and the PMA-231).
- SEPM/Level of effort[5] (SEPM/LOE) and retrofit support unit costs are based on the assumption that four aircraft will enter the SLEP/MOD process every year.
- Unit costs are calculated as "stand alone" costs; that is, it is assumed there is no simultaneous new production. There would be cost savings on SLEP/MODs that occur while the current production contract is in place due to the sharing of SEPM/LOE and production support costs.
- Costs were estimated using a "low estimate/most likely estimate/high estimate" methodology to reflect uncertainty regarding the ability to refurbish major components and the ability to properly define or specify all requirements.

Other specific assumptions are raised in the discussion of the individual SLEP/MOD cost elements, which follows.

SLEP/MOD Cost Elements

The discussion now turns to each of these cost elements and contrasts the CEC costs for those elements with the costs for the RMP. A summary of each SLEP/MOD element as it relates to cost estimates appears in Table 5.2.

Modifications. Table 5.3 shows low and high cost estimates for the CEC and RMP modifications and the most-likely estimates that fall within that range. The CEC estimate is from AIR 4.2 and is based on a previously modified E-2C. (The content of the modification estimate

[3]AIR 4.2 is the NAVAIR office responsible for cost estimates and analysis.

[4]AIR 4.3.3 is the NAVAIR office responsible for aircraft structural issues.

[5]*Level of effort* is a cost-estimating method that involves counting the number of people who have a specific skill required to perform a job.

Table 5.2

SLEP/MOD Element Activities Relating to Cost

Element	Related Activities or Definition
Modifications	Comprises aircraft alterations required for integrating the new electronics equipment. Includes airframe rework, wiring changes, replacement airframe components, and testing.
SLEP	Strictly speaking, this element comprises the correction of aircraft fatigue and related deficiencies in order to extend the specification life (in hours) of the airframe. In terms of cost, this element also includes the collection of repair items that would be corrected at the time of a SLEP/retrofit. Examples range from cold-working rivet holes to remanufacturing the rear of the fuselage.
Electronics equipment	Includes new-capability electronics equipment being installed as part of the retrofit.
Installation	Includes the removal of outdated electronics equipment and installation of updated electronics equipment. Also includes testing and checkout.
SEPM/LOE	Comprises the LOE engineering and analysis activities that support ongoing SLEP/retrofit and fleet operations. Those activities include system engineering, program management, fleet support, material support, and other engineering activities. Also included is SEPM for several activities charged directly to the E-2C program.
Support	Captures production and logistics support activities that are assumed to continue during the SLEP/MOD phase.

consists primarily of structural changes to the airframe to accommodate the new electronics.) Labor, material, overhead, and fees for contractor work are included.

The RMP estimate is less certain than the CEC estimate. Exactly what the modification entails is in a state of flux, with current assessments indicating that significant modification to the fuselage or a new fuselage, and also perhaps a new WCS, may be required.[6] The driving issues are the accommodation of the electronic equipment and the

[6]Modification approaches that involve replacing bulkheads and longerons have been deemed too risky and expensive, and often lead to excessive tooling and difficulty in maintaining fuselage shape characteristics.

Table 5.3

Average Unit Modification Cost Estimates, All Group II E-2Cs (in millions of FY2000 dollars)

	Low Estimate	Most-Likely Estimate	High Estimate
CEC	10.6	10.6	10.6
RMP	18.0	19.0	24.0

anticipated 2,500-pound airframe weight increase from the modification.

We assume that the RMP SD&D will produce a new fuselage design that can accommodate the CEC as well as all RMP requirements. The WCS will be either new or enhanced. If it is new, it will be charged to the "high estimate" modification case. Enhancements are charged to the "low estimate" and "most-likely estimate" SLEP cases (discussed later in this chapter). Development cost risk is born by the RMP SD&D. Fuselage and WCS estimates are based on information from NGC, adjusted for SLEP assumptions regarding the wing center section.

Structural Life Extension Program. The SLEP cost element contains both fatigue-life and repair-related costs. The costs were developed through discussions with AIR 4.3.3, AIR 4.2, and NGC, through comparisons with the C-2 SLEP, and through our own cost-modeling efforts. A wide difference of opinion exists as to what the SLEP work content requirements will be, leading to a wide range of cost estimates. We have resolved the high and low estimates by putting forth a "most-likely" estimate under the assumption that further discussion will result in a revised estimate that falls somewhere in between the low and high figures.

The estimated schedule for the CEC SLEP is two years for nonrecurring design engineering, eight months lead-time for parts procurement, and 18 months to complete the SLEP/retrofit. To make the best use of the program as a production "gap-filler" for NGC–Saint Augustine as the current production contract tails off, a nonrecurring start in 2002 is indicated.

The RMP technology will not be available earlier than 2008. Nonrecurring SLEP requirements over and above those addressed in

the CEC could be accomplished concurrent to the RMP development. These concurrent activities would affect the RMP SD&D in that the SD&D's focus on new aircraft design and production would have to be broadened to include the requirements of the airframes being SLEP/modified. We now briefly review the nonrecurring cost estimates for SLEP and then discuss the recurring cost estimates in some detail.

Based on our review of the C-2 SLEP and our discussions with NGC and AIR 4.3.3, we estimate that the total *nonrecurring costs* of the SLEP (for example, design costs) will fall in the $30 to $50 million range. The uncertainty in the estimate stems from lack of a clear definition of the total required design work. The required work has a complementary aspect—further analysis of the fatigue-life issues may result in less time expended in designing the modification kits and a lower per-unit SLEP cost. This lowered cost, taken across the E-2C fleet, would justify increased nonrecurring costs.

We next examine the SLEP elements in terms of their recurring costs, such as the costs of labor and materials and the overhead costs required to sustain production of SLEP/MOD E-2Cs. Table 5.4 lists estimated recurring costs for each CEC and RMP SLEP activity.

Table 5.4

SLEP Average Unit Recurring Cost Estimates (in millions of FY2000 dollars)

	CEC Cost Estimates			RMP Cost Estimates		
SLEP Item	Low	Most-Likely	High	Low	Most-Likely	High
Fuselage	0.1	0.5	2.9	N/A	N/A	N/A
Nacelles	0.1	0.2	0.3	0.1	0.2	0.3
Wing center section	0.1	0.3	1.7	0.1	0.5	N/A
Empennage	0.1	0.9	2.7	0.1	0.9	2.7
Outer wing panels	2.6	2.6	2.6	2.6	2.6	2.6
Pylon	0.1	0.2	0.3	0.1	0.2	0.3
Wiring	1.0	1.5	2.0	N/A	N/A	N/A
Landing gear	0.1	0.3	0.5	0.1	0.3	0.5
Obsolescence	0.3	0.4	0.5	0.3	0.4	0.5
Rotodome	0.1	0.5	1.0	N/A	N/A	N/A
Total	4.6	7.4	14.5	3.4	5.1	6.9

NOTE: Cells noted with N/A reflect new items that have zero SLEP costs.

Fuselage—The range of cost estimates for the CEC fuselage represents our view of the AIR 4.3.3 description of the work content (the low estimate), the NGC position (the high estimate), and an analogy to the SLEP costs experienced on the C-2 program (the most-likely estimate). The low estimate provides for cold-working and other minor structural repair. The high estimate includes re-skinning the rear fuselage and is a result of applying prior RAND estimating technology.[7] The cost estimate is based on a rough estimate of the new weight that is replacing the old weight during the SLEP (10 percent of the fuselage, or 566 pounds). The range of estimates is large, but further analysis and discussion should reduce that range. We think the C-2 experience is the best measure of the final outcome. We assume that the RMP will include a new fuselage, as stated earlier. Hence, there is no SLEP cost for this element under the RMP upgrade.

Nacelles—The range of cost estimates for both CEC and RMP reflects minor repair to the nacelles (engine enclosures) at the low end to replacement of the nacelles at the high end. The most-likely estimate is based on the assumption that moderate work will be required.

Wing Center Section—The CEC work on the WCS ranges from minor rework with the low estimate to significant repair, including re-skinning of the WCS, with the high estimate. The most-likely estimate provides for removal and rework by using cold-working. This is another case in which the analysis leading up to the SLEP will likely make a significant difference in the actual cost.

[7]Cost-estimating relationships for aircraft modifications were published in Birkler and Large (1981). The data from which these estimating relationships were derived are pertinent to the E-2C because of its 1960s origin. To apply these estimating relationships, we calibrated them to E-2C modification and production experience, in accordance with the process described by Birkler and Large. The following table compares the nominal published factors to the results of our calibration:

Factor	Nominal Value	Calibrated Value
Engineering	0.75	0.6
Tooling	0.5–1.0	0.25
Production	1.0	0.8
Quality control	0.07–0.17	0.1
Material	1.0	1.0
Cost improvement curve	0.77	0.95

The RMP includes cold-working of the WCS at the low-estimate end, removal and strengthening as the most-likely cost estimate work, and replacement of the WCS at the high-estimate end (included in modification cost).

Empennage—The estimates for this element are the same for both the CEC and RMP alternatives. The low estimate is for minor rework, and the high estimate provides for replacement of the empennage (tail assembly) if the fatigue life cannot be sufficiently extended through repair. The most likely estimate provides for substantial rework and was derived from the Birkler-Large (1981) methodology using replacement of 20 percent of the weight (or 228 pounds) as the parameter for the most-likely scenario.

Outer Wing Panels—The life of these components cannot be economically extended to 15,000 hours for either the RMP or CEC. They must be replaced before 10,000 hours. The estimate is the cost for a pair of new panels, based on AIR 4.2 data. NGC's costs were comparable to the AIR 4.2 estimates.

Pylon—This structure connects the rotodome antenna to the fuselage. The CEC estimate range equals the RMP range. We are including cost estimates for pylon SLEP as part of the entire estimate as a contingency against possible SLEP rework/replacement.

Wiring—The wiring estimate for the RMP is zero because we assume that the new fuselage and extensive WCS work will automatically provide new wiring. For the CEC, we developed a range based on the C-2 estimate.

Landing Gear—The range is the same for both CEC and the RMP. Fatigue life is not an issue because testing has shown that the landing gear can last until the 15,000-flight-hour level. However, corrosion and the gear eventually wearing out must be addressed. The low end of the cost-estimate range addresses maintenance actions while the high end covers replacement. The most-likely estimate is an average of the end points. If the increased aircraft weight of the RMP requires a new landing gear design, the cost could exceed the high range.

System Hardware Obsolescence—This cost element provides for the replacement of hardware items that can no longer be maintained economically, primarily due to age and out-of-inventory status. The

SLEP/MOD activity is an opportune time to deal with these issues; therefore, a contingency fund is set aside for that purpose. The FY2000 Operations and Support Modification Kit procurement estimate of $565,000 has been used to estimate the amount of this contingency fund. The SLEP/MOD itself will replace many pieces of equipment, reducing the requirement for obsolescence rework done as part of the SLEP.

Rotodome—The rotodome is the rotating antenna on top of the E-2C. A new rotodome is part of the RMP upgrade; therefore, no SLEP cost was calculated for the RMP. For CEC, the rotodome has no identified fatigue life issues, but corrosion failures have been identified. The range of estimates reflects the range of SLEP activities, from minor maintenance to removal of the antenna and its installation in a new canister. The estimates are based on AIR 4.2 actual costs, as analogies to the cost of a new rotodome.

Electronics and Installation. The estimated CEC electronics and installation costs are summarized in Table 5.5 for each configuration of Group II aircraft (the table is organized like Table 5.1 in terms of defining the Basic, NAV, and MCU aircraft groups). These data are based on information provided by AIR 4.2. In the table, NAV refers to the group of aircraft that already has the navigation package installed and MCU refers to the group of aircraft that already has the navigation package installed as well as mission computer upgrades. The

Table 5.5

E-2C Group II Aircraft Primary CEC Retrofit Electronics and Average Unit Cost Estimates (in millions of FY2000 dollars))

	Basic	NAV	MCU
Retrofit			
Navigation upgrade	X	N/A	N/A
Main computer upgrade	X	X	N/A
Cooperative engagement capability	X	X	X
Estimated Unit Costs			
Electronics cost	11.2	10.1	8.5
Installation cost	4.1	2.3	2.2
Number of Aircraft	23	18	6

Basic group receives the standard automatic flight control system, and both the Basic and NAV groups receive the mission computer upgrade and the advanced control indicator set. All three configurations receive satellite communications, a vapor cycle upgrade, electronic support measures, the CEC system, a power approach stability augmentation system, a main power distribution box, a fault reporting system, and aircraft change directives.

RMP cost estimates for electronics and installation are less certain than the CEC cost estimates because the system is still in development. RMP is currently assumed to include a new radar, rotodome, advanced IFF subsystem, advanced mission computer, advanced tactical workstations, advanced communications system, cockpit modifications, and generators. The cost estimates for RMP electronics and installation have been developed through discussions with AIR 4.2 and NGC and are summarized in Table 5.6. These costs are in addition to the costs for the MCU electronics package that provides the CEC capability ($8.5 and $2.2 million, as shown in Table 5.5) for all Group II aircraft because the RMP installation will replace the navigation and mission computer electronics that constitute the upgrades on the NAV and MCU aircraft groups.

The installation cost range in Table 5.6 reflects the uncertainty associated with the NGC–Saint Augustine facility's labor rates. Because RMP SLEPs cannot start until 2007, business forecasts are a concern. If the business base at Saint Augustine decreases from its current level, labor rates will increase. (The business-base issue is discussed in more depth in Chapter Six.) The high installation-cost estimate reflects the possibility of these higher labor costs.

System Engineering and Program Management/Level of Effort. This cost element was developed using an analogy to activities related to

Table 5.6

RMP Electronics and Installation Average Unit Cost Estimates (in millions of FY2000 dollars)

	Low Estimate	Most-Likely Estimate	High Estimate
Electronics cost	18.5	20.0	22.5
Installation cost	3.9	5.9	7.9

the NGC–Bethpage facility that support the current E-2C production. Table 5.7 lists the elements of the estimated costs for new production and SLEP retrofit for SEPM/LOE.

The system engineering/fleet support estimated costs are assessed to be about the same for new production and SLEP/retrofit because these activities would be required whether production or retrofit was being done. The program management/material support cost element is adjusted to account for the change in the nature of the work from managing the flow of primarily electronics materials for SLEP versus managing the wide variety of materials required for new production activities. Therefore, the SLEP/retrofit estimate is lower than the production estimate for this element because of the narrower range of materials being supported.

The row labeled "Other support" in Table 5.7 includes electrical wiring and fabrication of composite parts in addition to several smaller support activities. The SLEP/Retrofit values in the table reflect all of the support activities and a small portion of the electrical wiring work and fabrication of composite parts. The $35–$40 million range for the SLEP/retrofit represents the total cost per year. The total divided by the number of SLEP/retrofits per year (four) results in average unit cost values ranging from $8.5–$10 million for SEPM/LOE. The same values are used in the case of a CEC upgrade or the RMP.

SLEP/MOD Support. An annual production support value of $16 million was developed by analogy to the production support levels recently experienced by the E-2C program. It is assumed that the CEC and RMP SLEP/MOD programs will receive the same level of

Table 5.7

Estimated Costs for New Production and SLEP Retrofit for SEPM/LOE (in millions of FY2000 dollars)

SEPM/LOE Element	New Production	SLEP/Retrofit
System engineering/fleet support	25.7	25.7
Program management/ material support	16.3	7.2
Other support	14.3	6.0
Total	56.3	38.9 (35.0–40.0)

support. The $16 million total production support value is divided by four to calculate the $4 million per aircraft average unit cost that is used for all values in the cost range.

Acquisition Cost Summary

Table 5.8 summarizes the CEC SLEP/MOD cost estimates for the Basic configuration Group II E-2C aircraft.

Table 5.9 compares the CEC SLEP/MOD cost estimates for the Group II Basic, NAV, and MCU aircraft configurations. The major differences for the three variants are in the electronics and installation costs.

Table 5.10 summarizes the RMP SLEP/MOD estimated average unit costs for all Group II aircraft. The RMP modification introduces new navigation and computer equipment; therefore, the NAV and MCU aircraft have no cost advantage over the Basic aircraft.

Table 5.8

Average Unit Cost Estimates for CEC SLEP/MOD, Basic E-2C Group II Configuration (in millions of FY2000 dollars)

Cost Element	Low Estimate	Most-Likely Estimate	High Estimate
Modifications	10.6	10.6	10.6
SLEP	4.6	7.4	14.5
Electronics	11.2	11.2	11.2
Installation	4.1	4.1	4.1
SEPM/LOE	8.8	9.8	10.0
Support	4.0	4.0	4.0
Total	43.3	47.1	54.4

Table 5.9

Average Unit Cost Estimates for CEC SLEP/MOD, Three E-2C Group II Configurations (in millions of FY2000 dollars)

E-2C Variant	Low Estimate	Most-Likely Estimate	High Estimate
Basic	43.3	47.1	54.4
NAV	40.4	44.2	51.5
MCU	38.7	42.5	49.8

Table 5.10

Average Unit Cost Estimates for RMP SLEP/MOD, All E-2C Aircraft (in millions of FY2000 dollars))

Cost Element	Low Estimate	Most-Likely Estimate	High Estimate
Modifications	18.0	19.0	24.0
SLEP	3.4	5.1	6.9
Electronics	27.0	28.5	31.0
Installation	6.1	8.1	10.1
SEPM/LOE	8.8	9.8	10.0
Support	4.0	4.0	4.0
Total	67.3	74.5	86.0

The next section addresses the impact of O&S estimates on SLEP/MOD costs. The conclusion of this chapter combines acquisition and O&S costs for a total assessment of SLEP/MOD costs versus new production costs.

OPERATION AND SUPPORT COSTS ANALYSIS

In this section, we explain the methodology used to estimate operating and support costs for maintaining the E-2C inventory. The O&S analysis is based on a fixed number of E-2C aircraft in inventory, all of which have the same configuration. The only factor that changes in the O&S analysis is whether the aircraft are new acquisitions or are modified existing aircraft. The sole factor in the O&S cost difference between new and modified aircraft will be the age of the components that are *not* replaced during modification. Components replaced during modification will be of the same age as those on newly procured aircraft and therefore should incur the same O&S costs.

We expect equipment age to be related to maintenance costs primarily because of three conditions: fatigue, corrosion, and parts obsolescence. All three of these conditions affect the cost to upgrade or modify an E-2C. *Fatigue* is the weakening or failure of material from repeated stress cycles. Aircraft parts, particularly airframe structures and engine parts, are subject to stresses during use. Structural fatigue is the primary determinant of an aircraft's service life. *Corrosion* is the damage over time to metals caused by exposure to the environment. Corrosion control is part of the E-2C routine maintenance at the organizational level of maintenance (aboard ship). *Obsolete parts*

are parts constructed with outmoded technology or on production lines that have closed. Obsolete parts can take longer to replace or can be more costly to repair or replace than nonobsolete parts. The E-2C has a long list of obsolete equipment composed mostly of avionics items. These items, or the parts for them, are no longer available or are difficult to repair because they are made with outmoded technology.

Estimating the relationship between the age of aircraft components and the cost to operate and support an aircraft is difficult to do for a number of reasons. Components of various ages and various costs are interchanged among aircraft, making it difficult to ascertain the exact replacement costs for parts on an aircraft. Furthermore, the dollars spent on maintaining an aircraft over time can change due to resource availability, organizational changes, maintenance practices, and other factors. In fact, O&S funds spent in a given year by an organization are strongly affected by factors other than the age and condition of the equipment. These difficulties prevented our being able to estimate a specific relationship between the age of aircraft components and the cost to operate and support the E-2C.

Figure 5.1 illustrates how age-related O&S costs would behave over time, with a notional point at which aircraft are inducted for modification. Age-related costs would be greatest for an unmodified fleet of existing aircraft, as illustrated by the "Existing fleet" line in the figure. Modified aircraft would incur lower costs after the induction point because some of the aged equipment would be modified or replaced, and the age-related O&S costs of that equipment would be reduced to the same cost as that of new equipment. New aircraft would incur the lowest age-related O&S costs because all the equipment on the aircraft would be new.

O&S Cost-Estimating Approach

The methodology for estimating the O&S cost difference between new and modified aircraft is composed of five steps:

1. Identify age-related maintenance costs among total O&S costs.
2. Identify equipment not replaced during modification activities.

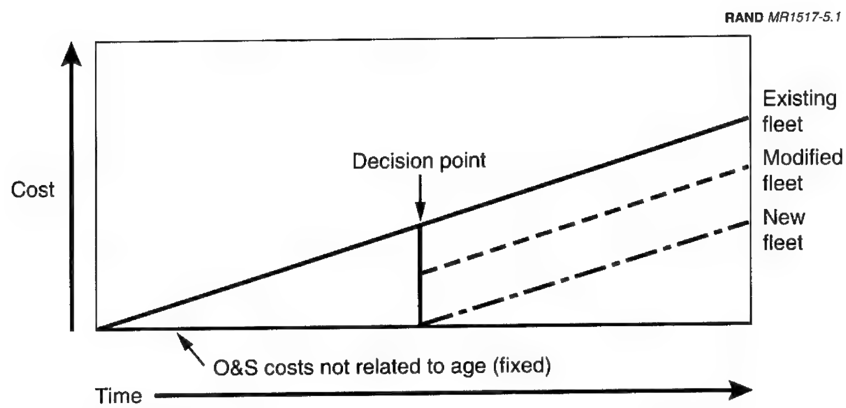

Figure 5.1—Age-Related O&S Cost Behavior

3. Determine maintenance costs (labor and parts) by equipment element.
4. Determine maintenance cost increase due to age.
5. Calculate maintenance cost increase by equipment element due to age.

Step 1: Establish Baseline Age-Related Maintenance Costs. Total O&S costs are defined by the O&S cost element structure required by the Office of the Secretary of Defense Cost Analysis Improvement Group. The cost element structure provides a standard set of definitions used by all Department of Defense services. The elements in that cost structure are shown in Table 5.11.

Total O&S costs for the elements listed in Table 5.11 were $7 million per aircraft per year based on a three-year average of E-2C costs from FY1996 to FY1998 (Crowley, 2001).[8]

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[8]The $7 million cost per unit includes $1.8 million for indirect support costs and reflects the increased emphasis on identifying total ownership costs of the E-2C program. O&S costs for weapons systems do not always include indirect support costs.

Table 5.11

O&S Cost Element Structures and E-2C Costs per Unit

Cost Element Structure	Cost (in millions of FY2000 dollars)
Mission personnel	**1.67**
Operations	0.41
Maintenance	0.89
Other mission personnel	0.37
Unit-level consumption	**1.55**
Petroleum, oil, and lubricants/Energy consumption	0.12
Consumable material/Repair parts	0.27
Depot-level repairables	1.13
Training munitions/Expendable stores	0
Other	0.03
Intermediate maintenance	**0.29**
Maintenance	0.17
Consumable material/Repair parts	0.12
Other	0
Depot	**0.96**
Overhaul/Rework	0.60
Engine repair	0.19
Other	0.17
Contractor support	**0**
Sustaining support	**0.76**
Support equipment replacement	0
Modification kit procurement/Installation	0.66
Other recurring investment	0
Sustaining engineering support	0.06
Software maintenance support	0.02
Simulator operations	0.02
Other	0
Indirect support	**1.80**
Personnel support	1.45
Installation support	0.35
Total O&S	**7.00**

NOTE: Those items with zero costs do not apply to the E-2C program.

Age-related maintenance costs were determined through a two-step analysis of the cost elements. In the first step, five of the seven major O&S cost elements (mission personnel, unit-level consumption, intermediate maintenance, depot, and sustaining support) were de-

termined to be potentially age related. These cost elements constitute 74 percent of total O&S costs for the E-2C.[9]

In the second step, major portions of the elements of mission personnel, depot airframe overhaul/rework, and sustaining support were excluded from being age related for the purposes of this analysis or because of certain factors related to the E-2C itself. The rationale for excluding each element is given in Table 5.12.

Table 5.12

Elements Excluded from Analysis of Age-Related Maintenance Costs

Cost Element	Reason for Exclusion
Operations personnel	These are personnel required to operate the E-2C aircraft. The specific mission, rather than age of the equipment, determines the number of required personnel.
Maintenance personnel	This element was initially judged to be sensitive to aircraft age. For carrier-based aircraft maintenance, however, the number of personnel in this element was reasoned to be largely insensitive to the age of aircraft and was excluded from the calculation for two reasons: (1) much of the workload is driven by routine maintenance, such as inspections and corrosion prevention and (2) staffing at the operations level is largely fixed. Reduced workload due to newer equipment would be more accurately described as cost avoidance rather than cost savings in that personnel would probably perform other maintenance tasks if they were not performing routine maintenance on E-2Cs. This is our assumption and not a Navy position.
Other mission personnel	Most of these individuals are headquarters personnel with an administrative and command function or are other personnel whose mission is not related to maintenance.
Petroleum, oil, and lubricants /Energy consumption	Fuel consumption depends much more on usage and equipment than on age.
Other unit-level consumption	This element contains temporary additional duty costs in the AIR 4.2 analysis, which are not related to equipment age.

[9]Percentages were calculated from the E-2C O&S costs reported in Crowley (2001).

Table 5.12 (continued)

Cost Element	Reason for Exclusion
Depot airframe overhaul and rework and other costs	These elements were initially judged to be related to age. However, the airframe will be overhauled and reworked extensively as part of the modification, and the cost of the modification is included in the procurement estimate. Depot costs were therefore excluded from the O&S estimate as age-related costs.
Modification kit procurement and installation	This cost element funds modifications to maintain readiness and improve flight safety. This element was excluded from the calculation of O&S cost savings because the SLEP/MOD program will improve the readiness and flight safety of the modified aircraft, so there will be no need for additional O&S-funded modification kits. Therefore, there will be little difference in age-related maintenance costs between modified and new aircraft.
Sustaining engineering support	The relationship of this element to age-related maintenance is unknown, but the LOE nature of this element suggests that it is not age related.
Software maintenance support	Software maintenance was excluded as age related for the reason that it is more a function of capability than age because software code does not deteriorate with time.
Simulator operations	This element was excluded because it is related to training rather than age.
Indirect support	Indirect support is a cost allocation for headquarters personnel, retirement funding, and other expenses that are only loosely related to the direct costs of the E-2C fleet. The costs are a function of total personnel and are insensitive to small changes in personnel numbers in the E-2 fleet.

Step 2: Identifying Equipment That Is Replaced or Not Replaced. Table 5.13 identifies by work unit code (WUC) and name the replaced or modified equipment that drives the top 70 percent of E-2C O&S costs. The table also indicates whether equipment was replaced for the CEC or the RMP alternative.

Step 3: Determining Maintenance Costs According to the Equipment Being Serviced. Maintenance costs by equipment were determined through a two-step process: (1) obtaining the proportion of equipment costs per O&S element and (2) applying the proportions to the total O&S cost, as described here. The proportion of equipment costs per O&S element was obtained from NAVAIR's Logistics

Table 5.13

Equipment Contributing to 70 Percent of the E-2C O&S Costs

WUC	Equipment Item	CEC	RMP	O&S Cost ($)	Percentage of Total O&S Costs	Cumulative Percentage of O&S Costs
223	T56 turboprop engine			47,594,670	16	16
726	APS-145 radar set		X	40,157,271	14	30
325	Variable pitch propellers	X	X	20,299,397	7	37
30	Maintenance inspections			18,859,872	6	43
728	Radar/navigation system computer group	X	X	13,782,817	5	48
29E	Power plant system			11,179,910	4	52
40	Corrosion preventer			10,752,324	3	55
724	APX-178/9 control indicator		X	7,784,928	3	58
734	Navigation system	X	X	7,774,588	2	60
761	ALR 59 or 73 countermeasures receiver set			5,706,362	2	62
111	Fuselage	X	X	5,478,315	2	64
631	UHF communications	X	X	5,133,620	2	66
135	Landing gear			4,474,474	2	68
13E	Landing gear			4,023,107	1	69
56X	Flight Reference Association equipment	X	X	3,725,345	1	70

Management Decision Support System (LMDSS).[10] The LMDSS was used to calculate cost proportions for each cost element rather than the absolute cost because the LMDSS database does not receive data from all fleet organizations and therefore the data do not reflect total

[10]LMDSS is a NAVAIR database that contains detailed organization and intermediate-level O&S costs. The costs are available for aircraft type/model/series (T/M/S) and by equipment detail for each T/M/S. The available data date back to 1999. Costs from calendar years 1999 and 2000 were taken from the LMDSS.

fleet O&S costs. The LMDSS data do, however, reflect the costs of labor and repair parts.

To capture all fleet costs for the E-2C, a yearly average based on O&S costs from FY1996 through FY1998 was used, as reported in Crowley (2001). The costs reported by Crowley were compared with those reported in the Visibility and Management of Operating and Support Costs (VAMOSC) database[11] and those costs were found to be similar. Proportional costs by equipment for each O&S element in the LMDSS were applied to the element cost total from the Crowley report to determine yearly maintenance cost by equipment.

Step 4: Determining Maintenance Cost Increase Due to Age. Based on prior RAND research, we are using an age-related compounded cost-growth rate of 2.3 percent per year per aircraft. This cost-growth rate is within the range found in other studies, most recently a study by the U.S. Congressional Budget Office, which found evidence of age-related cost growth of 1 to 3 percent per year for military aircraft (U.S. Congressional Budget Office, 2001).

However, some studies have suggested higher rates of O&S cost growth for military aircraft. We are reluctant to use higher rates of growth because of the difficulty in properly attributing cost increases to age. Cost increases attributed to physical age could in reality be cost increases that are due to developments over time, such as changes in technology or capability, operational requirements, or organizational practices. A distinction such as this is important to this study because we are comparing the costs of alternatives that differ only with respect to age and are otherwise the same in all other respects that would drive O&S cost increases.

As a sensitivity measure, we used a 7 percent growth factor to test the effect on the results. This higher growth factor, as compared with the 2.3 percent per year per aircraft used in previous studies, resulted in higher O&S estimates for the SLEP/MOD alternatives and lower estimates for the new procurement alternatives but did not change the rank order of the cost-analysis results at the end of this chapter.

[11]The VAMOSC is a Navy-owned database used to maintain historical O&S cost information.

Step 5: Calculating the Maintenance Cost Increase by Equipment Due to Age. For the purposes of this analysis, O&S costs were calculated for the following four cost categories:

- Costs that are insensitive to age
- Costs of equipment that is modified or replaced
- Costs of equipment that is not modified or replaced
- Savings from the difference between the age of existing equipment and the age of the equipment being modified or replaced.

The O&S costs are based on FY1996 through FY1998 average annual E-2C costs expressed in FY2000 dollars. These costs were adjusted by the equipment reliability and maintainability improvements estimated by NGC. The improvements resulted in an estimated 8 percent savings in the CEC O&S costs compared with the O&S costs of the current fleet and an additional 8 percent savings in the RMP O&S costs compared with aircraft with CEC (Northrop Grumman Corporation, 2000).

The O&S costs were calculated for each of the four cost categories over a ten-year period following modification. (Ten years is the approximate additional service life of a SLEP aircraft.) The age-sensitive calculations are sensitive to the time period over which the costs are calculated; that is, the age in years at modification plus the number of years after modification. In this analysis, the average age of an aircraft at induction was calculated to be 23 years. This age is derived from a schedule based on four inductions per year starting no sooner than the 8,000-flight-hour point.

The O&S costs that are insensitive to age are the total maintenance cost elements determined to be age insensitive in Step 1 of the O&S cost-estimating methodology.

The O&S cost of equipment being modified or replaced was calculated using several steps. Both modified and replaced equipment is considered new in terms of age, but because our available data are from the fleet in FY1996 through FY1998, we cannot determine the O&S costs of new E-2C equipment. Our major premise is that the O&S costs of equipment are "moving targets" that depend on the age of the equipment.

The first step in calculating the O&S cost of equipment being modified or replaced is to determine the average E-2C age during the FY1996 through FY1998 period that is the basis for our average annual O&S costs. The average age of aircraft in the fleet was readily calculated from aircraft delivery schedules.

Next, we were interested in the O&S cost of the equipment when it was new. To determine this cost, we assumed that the O&S costs had been rising due to age at 2.3 percent per year over the lifetime of the E-2C. We then used the 2.3 percent annual growth rate factor in reverse for the lifetime of the equipment to calculate the estimated (reduced) cost of the equipment when it was new. Having calculated the O&S cost of new E-2C equipment, we used the 2.3 percent annual growth rate factor to increase the yearly cost over ten years, which is the time period of interest.

The major equipment cost drivers for replaced or modified equipment include the following:

- Digital data converter
- Radio frequency amplifier
- Variable pitch propeller
- Azimuth range indicator
- Inertial measurement unit
- Propeller control assembly
- Variable pitch aircraft propeller system
- Displacement gyro
- Digital data computer
- Azimuth range indicator
- Engine accessories installation
- Digital data converter
- Equipment related to wing tip light cover
- Digital display
- Power driven rotary pump

- Nacelle induction system installation
- Radar modulator
- Equipment related to air cooling turbine
- Equipment related to landing gear tires
- Trigger pulse amplifier
- Radio frequency power meter
- Main landing gear wheels/tires.

The cost of equipment that is neither modified nor replaced was calculated using a rationale that is consistent with the one we just described for new or modified equipment. We began with the FY1996 through FY1998 average annual cost of the equipment and determined the average age of the fleet during that time. Then we calculated the average (older) age at the time of induction into the modification process and estimated the (increased) cost of the equipment at the time of induction by using the 2.3 percent growth factor. Finally, we increased the yearly O&S cost of the equipment over ten years using the 2.3 percent growth rate factor to determine the O&S cost during the period of interest.

The cost savings due to aged equipment that is not modified or replaced were calculated by subtracting the estimated cost of new equipment not replaced from the estimated cost of aged equipment not replaced over the ten-year period following induction.

O&S Cost Results

Both the CEC and RMP options provide for equipment that is forecast to be more reliable than existing equipment and should result in O&S costs that are lower than those incurred by the current fleet. The RMP alternative replaces a larger amount of equipment with greater savings from forecasted reliability and thus the RMP incurs a lower total O&S cost than does CEC. Both programs retain the existing aircraft engines, which contribute significantly to O&S costs. The CEC modification would save roughly $0.5 million per aircraft per year in O&S costs when compared with retaining all current equipment for ten years.

O&S Cost Summary

Table 5.14 summarizes the O&S cost results per aircraft for the CEC and RMP alternatives. The first row of the table shows average annual costs in constant FY2000 dollars over the ten years of life following modification. Because the O&S costs are over a time stream, the second row shows the average annual costs in discounted dollars. The discount rate is the 3.2 percent rate mandated by the Office of Management and Budget in circular A-94. The constant FY2000-dollar costs are of greater interest for programming and budgeting purposes than the discounted dollar costs. However, the discounted costs are presented here to sum them with procurement costs to produce the total cost summary at the end of this chapter.

O&S Cost Observations and Conclusions

The O&S estimates presented in this chapter contain a significant amount of indirect costs ($1.8 million per aircraft), which reflects a general trend in emphasizing O&S cost estimating in system total ownership costs. The per-aircraft estimates are therefore significantly higher than the O&S estimates without this large indirect-cost element. The indirect costs in addition to personnel, sustaining support, and depot costs were judged in the context of the E-2C program to be insensitive to equipment aging and are therefore constant across the CEC and the RMP new-aircraft and SLEP alternatives. These age-insensitive elements amount to roughly $5 million per aircraft—the bulk of O&S costs.

Table 5.14

O&S Cost Results per Aircraft (in millions of FY2000 dollars)

	CEC		RMP	
	SLEP	New Procurement	SLEP	New Procurement
Average O&S cost per year	7.0	6.5	6.6	6.3
Discounted average O&S cost per year	5.9	5.4	5.6	5.3

OVERALL COST ANALYSIS RESULTS

Table 5.15 presents the procurement and O&S costs for four E-2C alternatives: CEC SLEP modification, CEC new procurement, RMP SLEP modification, and RMP new procurement. The table shows procurement and discounted O&S costs in millions of dollars and shows the cost of buying one additional hour of aircraft life for procurement and O&S in thousands of dollars for all four options. SLEP/modification costs reflect the most likely cost for upgrading of the Group II Basic configuration. O&S costs are expressed in discounted dollars to allow a logical summation with procurement costs, which are incurred at the beginning of the ten-year period.

COST ANALYSIS OBSERVATIONS AND CONCLUSIONS

The cost analysis in this chapter compared the procurement and O&S costs for the CEC and RMP E-2C alternatives. The CEC and RMP alternatives offer different equipment and different capabilities at different costs. Therefore, the decision on which configuration to select must take into consideration differences in operational capa-

Table 5.15

Overall Cost Analysis Results

	CEC		RMP	
	SLEP/ Modification	New Procurement	SLEP/ Modification	New Procurement
Life in flight hours	5,000	10,000	5,000	10,000
Flight hours per year	480	480	480	480
Procurement cost ($M)	47.1	80.0	74.5	90.0
Discounted O&S cost per year ($M)	5.9	5.4	5.6	5.3
Procurement cost per flight hour ($K)	9.4	8.0	14.9	9.0
O&S cost per flight hour ($K)	12.3	11.3	11.7	11.0
Total cost per flight hour ($K)	21.7	19.3	26.6	20.0

NOTE: The new procurement cost estimates are rounded to the nearest ten million dollars to avoid disclosing government cost positions.

bility of the aircraft, which is beyond the scope of this analysis. Modifying the CEC configuration is significantly less expensive (about 20 percent less) than modifying the RMP configuration but offers less operational capability.

The choice between modification and new procurement for each configuration is a decision between alternatives with the same equipment and operational capability. The new and modified aircraft differ only in their expected service lives—10,000 hours for new aircraft versus 5,000 hours for SLEP/modified aircraft. Table 5.15 presents costs using the metric of cost per hour of service life. Calculating the costs in this way normalizes the new and modification alternatives to a comparable basis. The cost-per-hour results show that modification of aircraft to the CEC configuration is 13 percent more expensive than new procurement. Modification to the RMP configuration is the costliest alternative; it is 33 percent more expensive than buying new RMP aircraft.

Although this analysis has shown how the costs of the alternatives differ in absolute terms using the metric of cost per hour of service life, many factors influence the decision of whether to SLEP/MOD the existing fleet of E-2Cs or procure new ones, including availability of funds, inventory management, and industrial base issues.

Chapter Six

INDUSTRIAL BASE CONSIDERATIONS

In a previous study of the E-2C industrial base (Younossi et al., 2001), RAND analyzed the consequences of a two-year production gap for the NGC–Saint Augustine facility and for the firms that supply components for the E-2C. That study found that there would be significant economic, business, and workforce issues for NGC–Saint Augustine and its suppliers should such a gap occur. It is uncertain whether many of these suppliers could survive a production gap or would re-enter E-2C production once that production resumed.

For this study, we revisited some of the industrial base issues explored in the 2001 study to understand how a modification program might change the business outlook for NGC–Saint Augustine and its suppliers. In this chapter, we examine the workload outlook at Saint Augustine and qualitatively discuss the implications of a modification program for E-2C suppliers.

BACKGROUND ON NGC–SAINT AUGUSTINE

The Saint Augustine site, located 40 miles southeast of Jacksonville, Florida, is part of the Integrated Systems Sector of the Northrop Grumman Corporation. One of the site's primary missions is to manufacture, integrate, test, deliver, and modify E-2C aircraft. The site consists of 30 buildings on approximately 208 acres with nearly one-half-million square feet of manufacturing space and associated facilities to support flight operations. The site employs roughly 1,000 people full time. In addition to the E-2C work, the site supports modification of EA-6B, F/A-18, and F-5 (for the Naval Reserves) air-

craft. NGC–Saint Augustine also produces kits and spare parts for various other programs.

Workload Outlook

The NGC–Saint Augustine facility stands at a critical crossroads. With no planned follow-on to the multiyear production contract for the E-2C and much of the future support and maintenance work going to the Navy depots, the site's anticipated workload is forecasted to decline from more than 1.4 million hours per year to fewer than 0.4 million hours per year by 2006. Because E-2C production accounts for the majority of the workload at Saint Augustine, such a precipitous decline in work hours will result in significant layoffs and call into question the continued viability of the Saint Augustine site. In addition, some of the support facilities may have to be sold or closed.[1]

Figure 6.1 shows the fraction of the site's anticipated workload that E-2C production represents for 2001 through 2007 (between 60 and 70 percent). Clearly, any change in E-2C work levels would have a significant impact on the site.

Implications of a Modification Program

A good indicator of a production facility's economic health is its projected workload (in hours or worker head count). A steady or moderately growing workload portends a positive business outlook and signifies efficient throughput. Conversely, workloads that change rapidly, oscillate, or decline steeply can foster myriad problems (layoffs, inefficiency, loss of learning, closure or sale of a facility, or possible labor shortages). To understand the impact of a SLEP/MOD program on NGC–Saint Augustine, we forecasted workload levels under various production scenarios.

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[1]These workload numbers reflect the most current information we had available during the study. Notional gap-mitigation plans currently are under consideration by the Navy. However, none of these plans is as yet official.

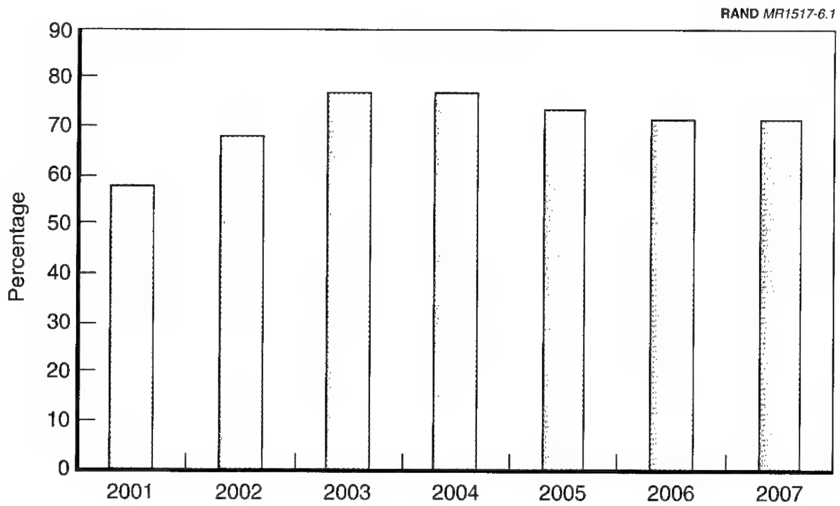

Figure 6.1—Percentage of Anticipated NGC–Saint Augustine Workload Attributable to E-2C Production

For this analysis, RAND asked NGC to provide detailed workload data, based on its experience, on producing new E-2C aircraft and modifying E-2Cs. Given the limited time and data that were available, NGC was able to provide only rough order-of-magnitude estimates based on a specific throughput. The NGC data assumed a production rate of four new aircraft or four SLEP/MODs per year and that the E-2C programs are stand-alones (either new production or modification but not both). While these data were not ideal, we were nevertheless able to use them to make our workload forecasts.

We assumed that the workload would be uniformly distributed over the duration of E-2C production (18 months for SLEP/MOD and 24 months for new production), and we did not adjust the work estimates for an annual production rate. Therefore, it is important to emphasize that the forecasts are qualitative only and should not be used for cost analysis purposes. Given these limitations, we purposely omitted a number scale on the y axis of Figure 6.2, which shows the workload for five cases similar to those illustrated by Figure 4.2 in Chapter Four.

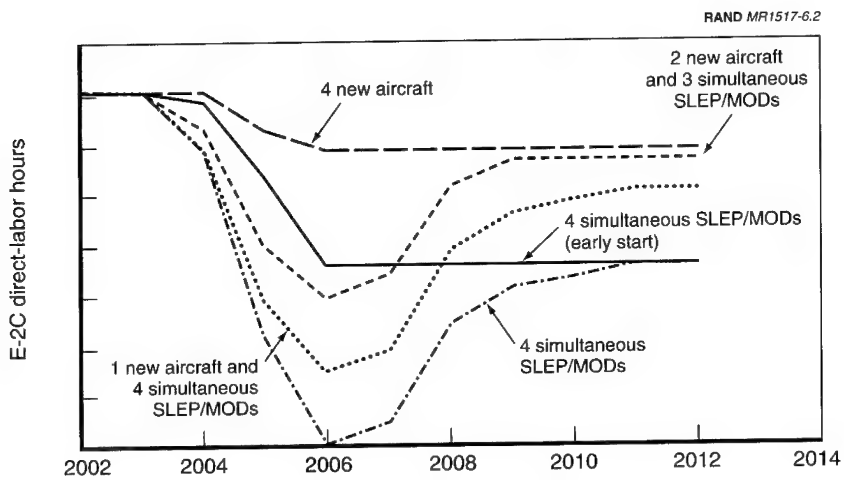

Figure 6.2—Workload Forecasts at NGC–Saint Augustine

Each line in Figure 6.2 represents a case of new production, modification work, or some combination of the two. The cases that include new production maintain the number of operationally available aircraft at or above the PAA level of 63 aircraft until 2025. We have assumed that any modification work is done to an E-2C Group II configuration and any new production is continuous so that no production gap occurs (presuming the new production is funded in fiscal year 2005, the year following the current multiyear production contract). Except for one case, modification work begins in 2007 (when the first Group II aircraft reach 8,000 flight hours).

The "Four new aircraft" line in Figure 6.2 depicts a continuation of new production at a rate of four new aircraft per year. Notice that there is a slight decline in the workload level following the period of the multiyear contract. The "Four simultaneous SLEP/MODs (early start)" line reflects a modification-only program in which the work begins in 2004. The "Two new aircraft and three simultaneous SLEP/MODs" line represents a case with a combination of modification work and new production. This case is based on two new aircraft per year plus three modifications. The "Two new aircraft and three simultaneous SLEP/MODs" line illustrates an option that is similar to the "2+2" option (a scenario with two new and two modified aircraft)

proposed by NGC as a production gap filler (see Younossi et al., 2001).[2] The "One new aircraft and four simultaneous SLEP/MODs" and "Four simultaneous SLEP/MODs" lines, which depict deep declines around FY2006, show lower rates of new production and modification work.

It is evident from Figure 6.2 that either some new production (following the multiyear contract) is necessary to prevent a large dip in the workload or the modification program must start in 2004.

The preceding analysis looks at total direct labor hours for the Saint Augustine site. However, new production and modification[3] (or retrofit) work differ in many ways. Specifically, the two activities employ different labor-skill mixes. Figure 6.3 shows the relative distribution of "touch" (hands-on) labor for new production and modification work.

New production uses a greater proportion of structural workers whereas modification work employs a greater number of other types of tradespeople, such as electricians and assemblers, as a percentage of total workers in each case. Although we do not have a similar worker-type breakout for a SLEP/MOD activity, we would expect that the proportions would fall somewhere between the new production and the modification work. For instance, the proportion of structural workers would end up somewhere between the new construction and modification work proportions.

EFFECT ON SUPPLIERS

The Younossi et al. (2001) industrial base study drew several conclusions about the major suppliers to E-2C production:

- Suppliers would face production gap issues sooner than the NGC–Saint Augustine facility would. Under the multiyear contract, the dates for final deliveries by suppliers range from November 2002 to June 2005.

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[2]NGC proposed a combination of two new aircraft and two HE2000 retrofits as a way of providing a sustainable workload for the Saint Augustine facility.

[3]Modification in this case refers to an avionics upgrade only without any significant airframe work.

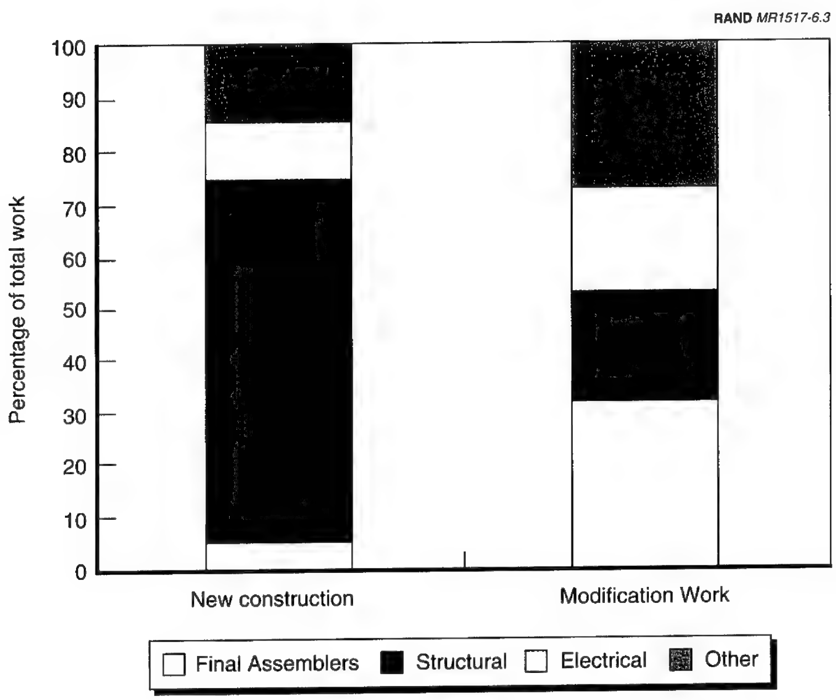

Figure 6.3—Proportion of Worker-Skill Types for New Production and Modification Work

- Many suppliers will experience restart delays after a production gap; current lead times for production restarts range from 12 to 20 months.
- Some suppliers may not survive the production gap, particularly the radar and rotodome suppliers.
- A production gap exacerbates obsolescence issues by delaying the production of new or modified aircraft.
- Alternative vendors are limited or are costly to introduce into the E-2C program.

One of the differences between a modification program and new production is that a large fraction of the missions systems and other equipment (particularly for the CEC modification) is reused. For ex-

ample, the radar vendor does not produce new equipment for the CEC modification, and it is unclear whether the rotodome vendor will be involved in any refurbishment of the rotodome. Therefore, a modification program does not provide any substantial work to the supplier base. Thus, many of the production gap issues remain for the suppliers even if modification work continues at Saint Augustine.

SUMMARY

E-2C new production represents a significant part of the business base of NGC–Saint Augustine. Therefore, facility divestiture or work consolidation at Saint Augustine may be necessary should a production gap occur. Although modification work would help to reduce the effects of any production gap, that work must begin by 2004 to have a beneficial impact. However, with a 2004 start, none of the aircraft will have attained the 8,000 cumulative flight hours that are the minimum before the SLEP/MOD can proceed.

In addition, modification work may be problematic in terms of the mix of labor skills at Saint Augustine. The labor-skill mix required to modify aircraft is different from that required to build new aircraft. For instance, a much higher percentage of workers with structural experience is required for new production (see Figure 6.3). Finally, a modification-only program does little to help the major suppliers and vendors as far as continued work or demand for their products.

Chapter Seven

CONCLUSIONS AND RECOMMENDATIONS

The current fleet of 67 operational E-2C aircraft comprises three different models and several variants within those models. The current fleet is based on aircraft that for the most part were delivered to the Navy during the late 1980s and early to mid-1990s. Many aircraft in the fleet are approaching their service life limits and this aging fleet will not be able to satisfy all of the Navy's future operational performance requirements.

To modernize and maintain the E-2C fleet, the Navy is buying 21 Hawkeye 2000 aircraft with cooperative engagement capability from Northrop Grumman Corporation, the E-2C prime contractor. In addition, the Navy is engaged in a new development effort, the radar modernization program, to further increase the E-2C's capability, enabling it to operate in littoral areas and over land as well as over water. Despite these modernization and production efforts, the E-2C fleet of available aircraft is projected to fall below the PAA level of 63 aircraft by 2013. Furthermore, several years will pass before the fleet has substantial numbers of CEC-equipped aircraft.

Our objective in this study was to define the range of options open to the Navy to extend the life of and modernize its E-2C fleet to better meet its future needs. We considered the following options:

- Extend the airframe life of the current fleet of aircraft and retrofit those aircraft that lack the CEC capability
- Procure additional HE2000s that already possess the CEC capability

- Extend the airframe life of the current fleet aircraft and retrofit the fleet with modernized radar with littoral capability (the RMP option)
- Some combination of life extension, retrofit, and buying new aircraft.

We performed a quantitative analysis of the effects of each option on the ability of E-2C inventory to meet the required 63 operationally available aircraft. We also assessed the life-cycle cost implications of each alternative. The results of our analysis produced the following:

- None of the life extension and retrofit options, or any combination of options, can sustain the minimum number of available aircraft out to 2025 unless the Navy buys some new E-2C aircraft.
- An RMP retrofit coupled with a life extension program is so expensive that it would be more cost-effective to buy new RMP aircraft.
- The RMP poses both technical and program challenges. The technical challenge is that the capability of the radar is yet to be demonstrated. The program challenge is that the 2,500 pounds of additional aircraft weight may significantly increase the program cost and threaten the development schedule because of the additional design and testing that are required.
- A relatively stable flow of E-2C work is essential to the survival of Northrop Grumman Corporation's Saint Augustine facility, and maintaining a workflow of that level is not feasible with SLEP/MOD program work alone.

From our analysis, we have the following recommendations:

- If the Navy wants to modernize its fleet with aircraft that possess CEC, then it should consider a combination of service-life extension plus CEC retrofit of two aircraft per year while also procuring two new Hawkeye 2000s. This is the most cost-effective option and it also maintains the fleet readiness levels at or above 63 while helping to address the NGC–Saint Augustine industrial base issue.

- If the Navy deems the littoral capability necessary for its future operations, then it should opt for service-life extension plus the CEC retrofit of the fleet combined with new production as a production-gap-mitigation strategy. This combination strategy would maintain the fleet's available aircraft level and preserve the industrial base, but only until the RMP program development is complete. However, additional airframe design and testing efforts to accommodate the RMP may require additional budgeted time and funding. The Navy should buy only new RMP aircraft because the RMP retrofit modification is likely to be overly costly. A new-RMP aircraft strategy would maintain readiness levels, would address industrial base concerns, and would provide additional performance capability to future warfighters.
- However, before spending additional money to modify the current E-2C airframe to accommodate the additional weight of the RMP, the Navy should consider the costs and benefits of a new E-2C airframe design. The new airframe design could provide additional opportunities for future enhancements and incorporate producibility improvements through modern design approaches and manufacturing techniques.

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he E-2C Hawkeye is the U.S. Navy's all-weather airborne early-warning aircraft and an integral component of the Navy's carrier air wing. Although some of the fleet E-2Cs are currently being replaced with an enhanced version of the aircraft, many E-2Cs are approaching their service life limits and the Navy is concerned about the aging fleet's ability to satisfy future operational performance requirements. The Navy soon has to decide whether to buy new aircraft, retrofit old aircraft or refurbish them to extend their service lives, or adopt some combination of these options. This book analyzes the costs, benefits, and risks of those options. The authors find that none of the life-extension and retrofit options can sustain the required minimum number of available aircraft over the long run unless the Navy also buys some new E-2C aircraft, and radar-modernization retrofitting coupled with a life-extension program is so expensive that it would be more cost effective to buy new aircraft already equipped with the upgraded radar. In addition, a steady flow of E-2C work is critical to the Saint Augustine facility of Northrop Grumman Corporation, the E-2C prime contractor, and maintaining such a workflow is not feasible with a life-extension program alone.

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